# Supporting Document for Greenhouse Gas Assessment Workbook for Road Projects

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**Transport Authorities Greenhouse Group**

Tasmania
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DEPARTMENT of INFRASTRUCTURE, ENERGY & RESOURCES

NSW GOVERNMENT
Transport Roads & Maritime Services

mainroads WESTERN AUSTRALIA

NZ TRANSPORT AGENCY
WAKA KOTAHI

Government of South Australia
Department of Planning, Transport and Infrastructure

vicroads

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Author: A Dilger / C Riley J Bengtsson ....................................................

Signed: ....................................................................

Reviewer: D Low / G Gilpin ..........................................................................

Signed: ..........................................................

Approved by: D Low ..........................................................................................

Signed: ..........................................................

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# Glossary

| | |
|---|---|
| Activity | An action that gives rise to an emission source and the release of greenhouse gases. |
| Assessment Boundary | In the context of estimating GHG emissions for a road project, the Assessment Boundary is considered to be: all of the GHG emissions from operations/activities over which the designers, constructors and operators have control. |
| Boundary | The boundary is an imaginary line around the emission sources and activities that are included in the GHG assessment. Emission sources and activities outside the boundary are excluded. |
| Carbon dioxide equivalent ($CO_2$-e) | The mass of a greenhouse gas that is emitted is multiplied by its global warming potential to convert greenhouse gas emissions to an equivalent quantity of $CO_2$ emissions, referred to as carbon dioxide equivalent.<br>For simplicity of reporting, the mass of each greenhouse gas emitted is commonly translated into a carbon dioxide equivalent ($CO_2$-e) amount so that the total impact from all sources can be summed to one figure |
| Construction | Construction is considered to be the time between obtaining development approvals and funding, and handing over the asset to the region operator and maintainer. |
| Conversion Factor | A numerical value to enable conversion from one unit of measure to another (e.g. a density conversion factor is used to convert a volume of a material to a mass of a material or vice versa) |
| Default quantity factor (DQF) | Default quantity factors convert an indicator of activity into estimated activity data quantities, which can be used in greenhouse gas emission calculations. |
| Design | Design is considered to be the time between conceiving the road project and obtaining development approvals and funding |
| Edge | Edge Environment |
| Emission | Refers to greenhouse gas emissions |
| Emission factor | A numerical value to enable conversion from a unit of measure to GHG emissions |
| Emission source | A source from which greenhouse gases are released |
| GHG | Greenhouse gas(es) |
| GHG Protocol | The World Resource Institute and the World Business Council for Sustainable Development's Greenhouse Gas Protocol: a corporate accounting and reporting standard |
| Greenfield | A project that lacks any constraints imposed by prior work |
| Greenhouse gas Assessment Boundary | The GHG Assessment Boundary defines which emission sources and activities are included in the assessment and which are excluded. |
| Greenhouse gases | Greenhouse gases are those gases which reduce the loss of heat from the earth's atmosphere by absorbing infrared radiation. Six greenhouse gases are regulated by the Kyoto Protocol: Carbon dioxide ($CO_2$), Methane ($CH_4$), Nitrous oxide ($N_2O$), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride ($SF_6$). The emissions of greenhouse gases are reported in carbon dioxide equivalents (see above). |
| km | Standard abbreviation for kilometre. A unit of distance. |
| $m^2$ | Standard abbreviation for square metre. A unit of area. |
| Maintenance | Maintenance is considered to be post construction and includes activities that are intermittently required to keep the road assets at the required standard. Maintenance can be major (i.e. rehabilitation), planned or reactive. |
| Major activity | Defined as design, construction, operation and maintenance |
| Materiality | Materiality is a measure of the estimated effect that the presence or absence of an emission source or activity may have on the accuracy or validity of a greenhouse gas assessment. |
| NZ | New Zealand |

| | |
|---|---|
| Operation | Operation is considered to be post construction and includes activities that are required on a continuous basis for the functioning of the road.<br>This Workbook does not include road usage by vehicles in this definition. |
| PB | Parsons Brinckerhoff Australia Pty Ltd |
| Pavement | The road surface and road base. |
| Project scoping | Development of the concept design and detailed business case. Tender documents would be issued at the completion of this phase if the project is to be delivered via a design and construct (D&C) contract. |
| Project development | Development of preliminary and detailed design. Submission of tenders would occur at the completion of this phase if the project is to be delivered via a D&C contract. |
| Project delivery | Project is awarded at the start of this phase if the project is to be delivered via a D&C contract. It includes construction of the road and project handover to the asset operator. |
| Post construction | The period after road construction is completed. |
| Road project life cycle | The life cycle considered in the Workbook is limited to the major activities of: design, construction, operation and maintenance |
| Road structures | Includes structures that may be included in a road project (e.g. bridge, tunnel, reinforced soil walls etc.) |
| Scope 1 emissions | Emissions released into the atmosphere as a direct result of an activity, or series of activities (including ancillary activities) that constitutes the facility. |
| Scope 2 emissions | Emissions released as a result of one or more activities that generate electricity, heating, cooling or steam that is consumed by the facility but that do no form part of the facility. |
| Scope 3 emissions | Emissions that occur outside the site boundary of a facility as a result of activities at a facility that are not Scope 2 emissions. |
| Supporting Document | This document, which provides information regarding the development of the Greenhouse Gas Assessment Workbook for Road Projects |
| Surface roads | Roads that only require pavement |
| t $CO_2$ | Tonnes of carbon dioxide (used for sequestration in vegetation) |
| t $CO_2$-e | Standard unit of measure for greenhouse house emissions. Tonnes of carbon dioxide equivalents |
| TAGG | Transport Authorities Greenhouse Group |
| TJ | Standard abbreviation for terajoule, a unit of energy equal to $10^{12}$ joules |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UOM | Unit of measurement |
| Workbook | Greenhouse Gas Assessment Workbook for Road Projects |

# 1. Introduction

In 2010 Parsons Brinckerhoff Australia Pty Ltd (PB) and Edge Environment (Edge) were engaged by the Transport Authorities Greenhouse Group (TAGG) to develop a Greenhouse Gas (GHG) Assessment Workbook (the Workbook) that could provide a consistent approach to estimating greenhouse gas emissions for road projects across their entire life cycle (design, construction, operation, maintenance).

This supporting information document is designed to sit behind the Workbook and provide additional background information to its users, if required.

This is the first update of the workbook, based on feedback from its initial publication.

## 1.1 Structure of the supporting information document

The Supporting Document follows the structure of the Workbook.

The Supporting Document includes the following sections:

- **Chapter 1:** Introduction to the Supporting Document
- **Chapter 2:** Greenhouse gas assessment methodologies. Presents recognised GHG assessment methodologies and outlines how these have been adopted in the Workbook
- **Chapter 3:** Greenhouse gas Assessment Boundaries. Presents the basis for setting the GHG Assessment Boundaries and the complete boundary for each significant major activity (construction, operation, maintenance)
- **Chapter 4:** Major emission sources and materiality.
- **Chapter 5:** Default quantity factors
- **Chapter 6:** Emission factors.
- **Chapter 7:** Time period for operation and maintenance assessments
- **Chapter 8:** Updating the Workbook
- **Appendices:** Provide additional figures and data used in developing the Workbook

# 2. Existing and adopted greenhouse gas assessment methodologies

In developing the methodology for estimating the GHG emissions from road projects a number of methodologies and approaches were reviewed. All methodologies were in part based on, or compatible with, the GHG Protocol Corporate Standard (the Protocol) developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD).

Whilst the Protocol has been developed for corporations to estimate the GHG emissions of an organisation, the Protocol Principles can also be applied to a road project and hence, the Protocol has been used as the basis of the GHG assessment Workbook methodology.

## 2.1 GHG Protocol Corporate Standard methodology

The Protocol was designed with the following objectives in mind:

- to help companies prepare a GHG emissions inventory that represents a true and fair account of their emissions, through the use of standardised approaches and principles.
- to simplify and reduce the costs of compiling a GHG emissions inventory.
- to provide business with information that can be used to build an effective strategy to manage and reduce GHG emissions.
- to increase consistency and transparency in GHG accounting and reporting among various companies and GHG programs.

Table 2.1 provides a summary of the Protocol Principles and references to the section within this document that addresses these Principles.

**Table 2.1 GHG Protocol Principles**

| Protocol Principles | Principles | Where addressed in this Supporting Document |
|---|---|---|
| Relevance | Ensure the GHG inventory appropriately reflects the GHG emissions of the company (project) and serves the decision-making needs of users – both internal and external to the company. | Section 3, 4 and 7 |
| Completeness | Account for and report on all GHG emissions sources and activities within the chosen inventory boundary.<br>Disclose and justify any specific exclusions. | Section 3 |
| Consistency | Use consistent methodologies to allow for meaningful comparisons of emissions over time.<br>Transparently document any changes to the data, inventory boundary, methods, or any other relevant factors in the time series. | Section 2.2 |
| Transparency | Address all relevant issues in a factual and coherent manner, based on a clear audit trail.<br>Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used. | Section 4, 5 and 6 |

| Protocol Principles | Principles | Where addressed in this Supporting Document |
|---|---|---|
| Accuracy | Ensure that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as practicable.<br>Achieve sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information. | Section 2.2.1 |

## 2.2 GHG assessment methodology for road projects

The methodology developed for the Workbook involves six steps as illustrated in Figure 2.1. This methodology was developed to align with the Protocol and the Protocol Principles outlined in Table 2.1. However, as the Workbook has been developed specifically for road projects and because it will be used by different road authorities, designers and contractors, the methodology must remain flexible and adaptable. For example, the Workbook does not prescribe how data should be documented or reported, as this will be determined by individual road authorities.

### 2.2.1 Limitations of the default quantity factors method and the accuracy principle

An additional series of sub-steps (Step 3a to 3c) have been incorporated into the methodology to account for the possible lack of emission source (usage) data and the potential need to use default quantity factors in the early stages of a project. This modification reduces the certainty of assessments in these early stages. However, given that the Workbook is not for trading or legislative purposes, this reduction in certainty is not considered to lessen the benefit of undertaking a GHG assessment at that time.

Further information regarding the default quantity factors is included in Section 4.

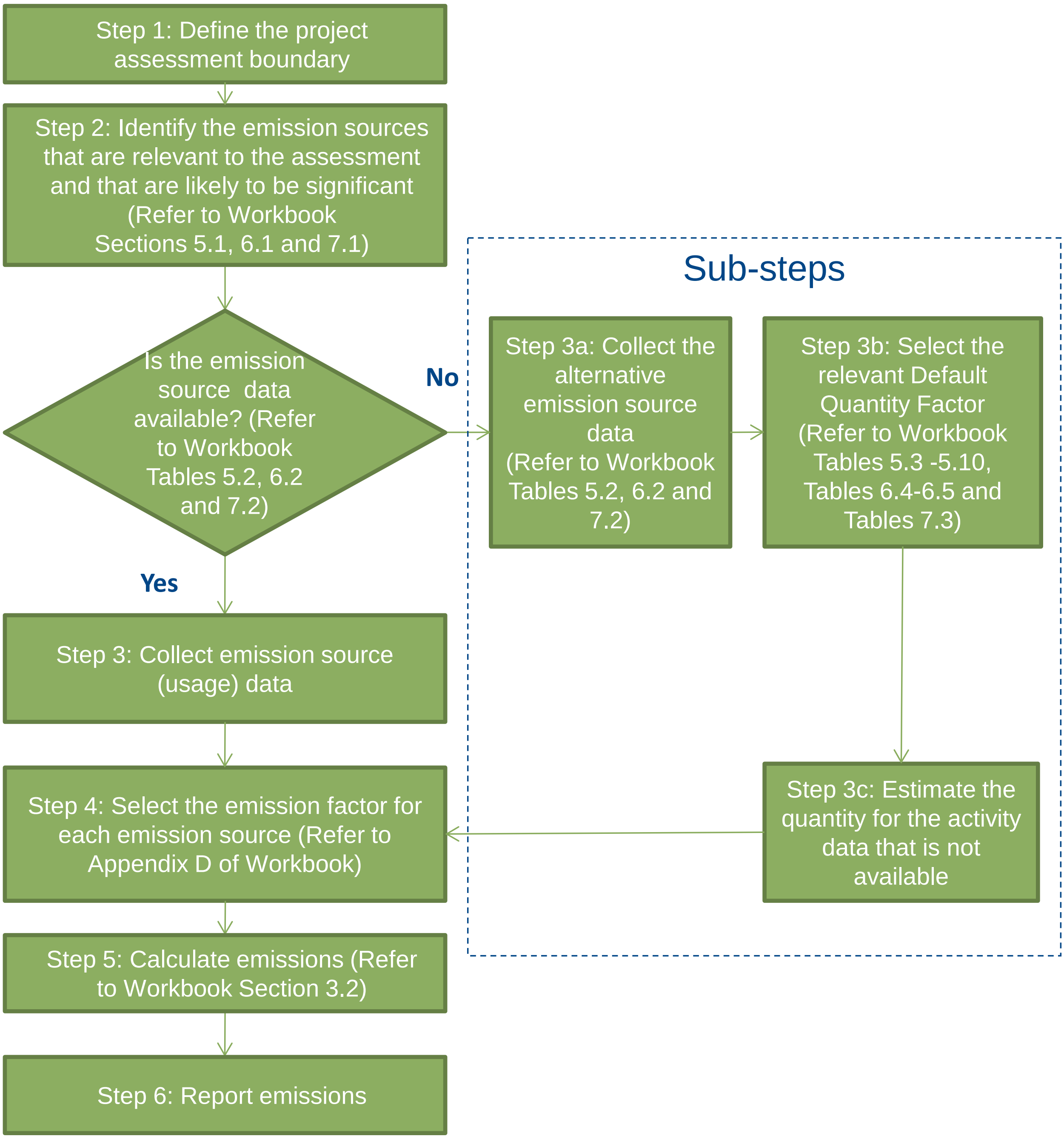


**Figure 2.1 Overview process for calculating GHG emissions**

# 3. GHG Assessment Boundary definition

It is important to define the scope of a GHG assessment both physically (i.e. identifying the processes and products that lie within the scope of the assessment) and temporarily (i.e. considering the period of time over which the assessment applies).

A fundamental principle of life cycle GHG assessments is that the mass and energy that flows into any system must equal the mass and energy that flows out as product, co-product, waste or pollution. It is therefore essential to map out the processes that lie within the system and define a clear boundary around the processes, and hence identify exclusions from the system. This is often referred to as the GHG system boundary. The Workbook refers to this as the GHG Assessment Boundary.

## 3.1 Overview

The method for defining the GHG Assessment Boundaries for the Workbook is aligned with recognised GHG assessment processes, such as the GHG Protocol, but has been tailored for road projects.

The GHG Assessment Boundaries have been defined by considering what the proponent can influence. This approach first requires the project scope to be defined, followed by the Assessment Boundary. In the case of an existing road, the **Project Scope** will be defined by the details of the road in question and the associated operational and maintenance requirements.

GHG Assessment Boundaries have been defined for each significant major activity of a road project (construction, operation and maintenance) to provide a consistent approach.

Design, as an activity, is not assessed within the Workbook, as it is insignificant in its ability to generate emissions. However, it is acknowledged that the design of a road is an activity which can have significant influence on the emissions associated with the other activities (e.g. construction, operation).

Refer to Appendix A for a list of emission sources considered when developing the GHG Assessment Boundaries.

## 3.2 Scopes of emissions

The GHG Assessment Boundaries take into consideration emission scopes. The GHG Protocol defines three scopes of emissions to ensure that single emission sources are not counted twice within the supply chain. A summary of the different scope categories is provided in Section 2.3.1 of the Workbook.

Scope 1 and 2 emissions are included in recognised GHG inventory reporting schemes and these emissions are therefore included within the GHG Assessment Boundary.

Scope 3 emissions are typically considered optional in some reporting schemes. However, it is recognised that the inclusion of Scope 3 emissions provide a more holistic view of a road project’s environmental impact. They also provide an opportunity to be innovative in GHG emissions management. The GHG Assessment Boundary therefore includes those Scope 3 emissions that are deemed to be pertinent and significant to road projects taking into consideration recognised standards such as the GHG Protocol and the National Carbon Offset Standard (Department of Climate Change and Energy Efficiency [DCCEE], 2010).

The Scope 3 emissions that were included in the complete GHG Assessment Boundaries are:

1. extraction, production and transport of purchased fuels
2. extraction, production and transport of purchased materials or goods
3. disposal of waste generated in the production of purchased fuels, materials and goods
4. outsourced activities (e.g. activities undertaken by sub-contractors)
5. cost of equipment, consumables, repairs, maintenance and communications relating to buildings and equipment
6. business travel of employees
7. disposal of waste generated by the project (including maintenance); and
8. use of paper in the course of its business.

Items 1–4 and 6–7 were included as Scope 3 emissions within the complete GHG Assessment Boundaries presented in Section 3.3.

## 3.3 Complete GHG Assessment Boundary diagrams

Figures 3.1 – 3.3 illustrate the complete construction, operation and maintenance GHG Assessment Boundaries, prior to the materiality assessments. Using a process flow diagram shows the individual processes and their inter-relationships and defines:

- Where the process begins, in terms of the receipt/extraction of raw materials or intermediate products
- The nature of the transformations and operations that occur as part of the process, and
- Where the process ends; the destination of the intermediate or final products.

The diagrams show the emission sources that are both included and excluded from the GHG Assessment Boundary. The respective diagrams in the Workbook include only those emissions sources that have been included.

**LEGEND:**

Activities with a coloured, dashed outline are those that may be significant for some road projects but insignificant for others.

Emission sources with a coloured box and dashed outline are those that may be significant for some road projects but insignificant for others.

Emission sources with no colour and a solid black outline are those that have been excluded from the GHG Assessment Boundary based on the materiality assessment, as they are insignificant.

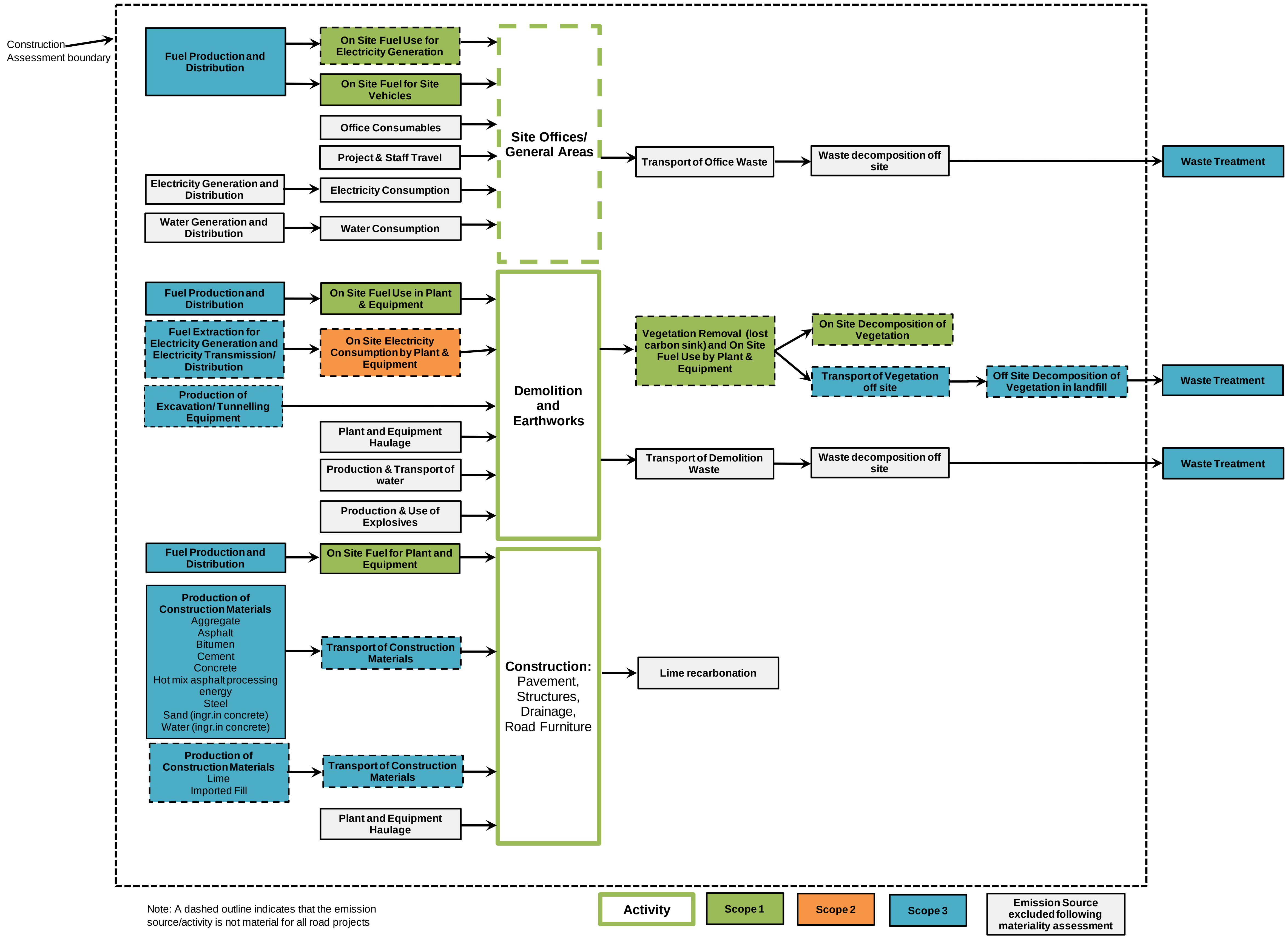


**Figure 3.1 Complete Construction GHG Assessment Boundary**

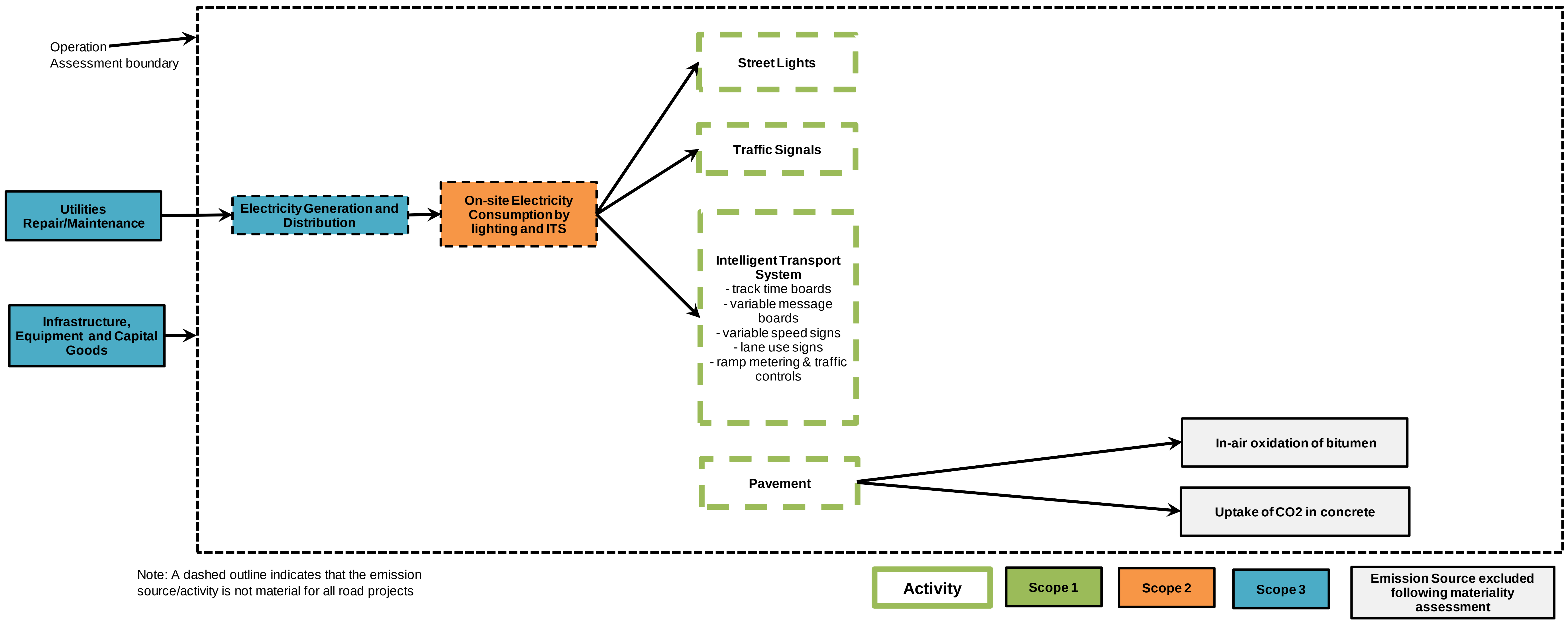


**Figure 3.2 Complete Operation GHG Assessment Boundary**

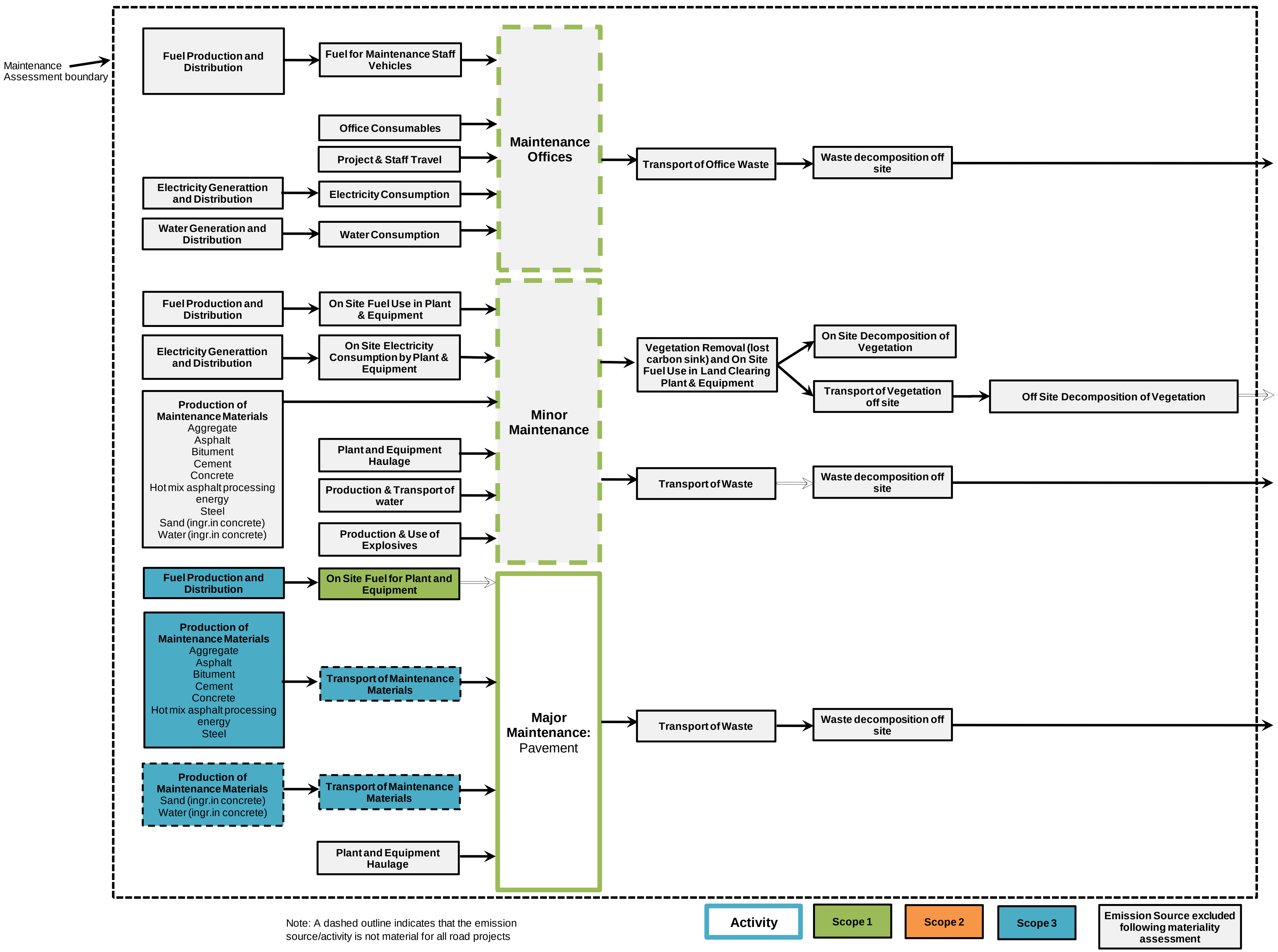


**Figure 3.3 Complete Maintenance GHG Assessment Boundary**

## 3.4 Materiality and major emission sources

Materiality is a measure of the estimated effect that the presence or absence of an emission source or activity may have on the accuracy or validity of a greenhouse gas assessment. It refers to the quantitative significance of an emission source's contribution to a project's overall GHG emissions.

The following section looks at the materiality of each of the major activities (design, construction, operation and maintenance) associated with a road project and then looks at the materiality of emission sources within each of these major activities.

Where possible case studies have been used in these assessments.

## 3.5 Materiality of major activities

Four international case studies were identified that included an assessment of the GHG emissions from construction and operation of a road (where operation does not include the GHG emissions from vehicles using the road). The proportions of the GHG emissions for construction and operation are shown in Figure 3.4.

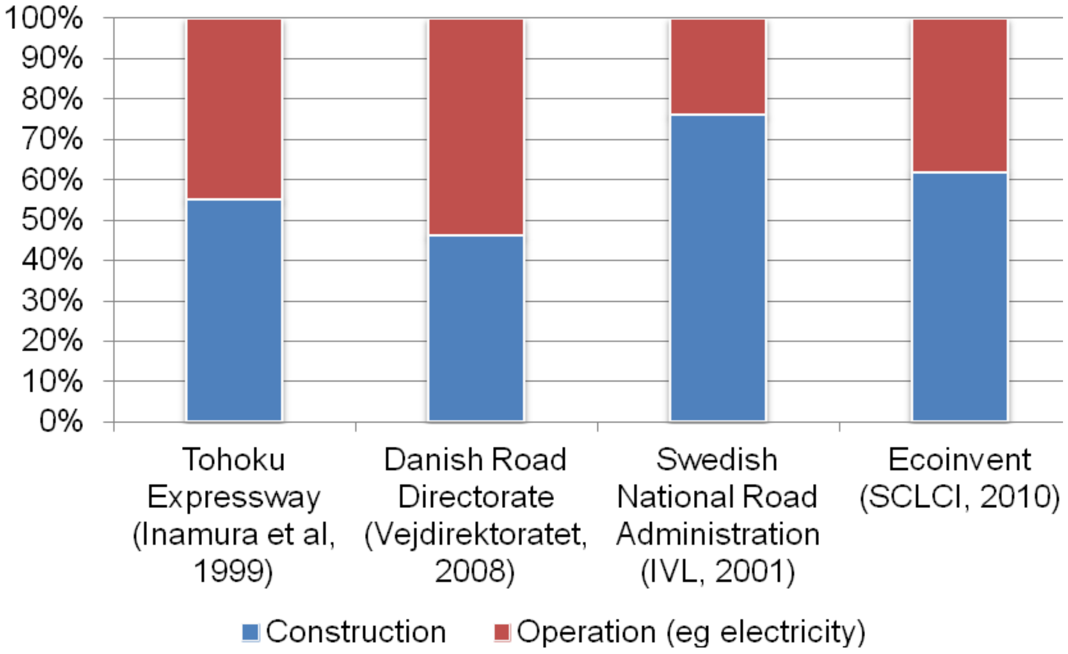


**Figure 3.4 Contribution of construction and operation to the GHG emissions for various road projects**

**Note:** GHG Emissions for the IVL Swedish Environmental Research Institute (Swedish IVL) case study have been re-calculated using the average of Australian emission factors for electricity.

The contribution of road construction ranges from 46% to 76%. However, the assessment period over which the operational energy consumption is assessed must be taken into account. The time spans used vary between studies from 40 years in the Swedish IVL study to 100 years for the Ecoinvent study. As the periods are over a time period similar to the one used in the development of the Workbook (50 years) the results from these studies are relevant in assessing materiality of construction and operation.

The GHG emission factors for electricity generation and distribution is another significant factor that will impact on the emissions from operation. For example, Swedish, Swiss and Danish electricity generation results in relatively low emissions (due to generation being predominantly from hydro, nuclear and wind).

These studies show that over a period of time (40 years +) the emissions from the operation of a road are approximately equal to the emissions from the construction of the road and therefore the operation of a road should be included in a GHG assessment.

Figure 3.5 shows the breakdown of the energy consumption for a number of road types considered in the Swedish IVL study, where 'cold mix asphalt road' refers to the method used to produce the asphalt (referred to as warm mix in Australia) and 'low emission vehicles' refer to the vehicles used to construct, operate and maintain the road. The grey boxes show the energy inherently bonded in the road materials but not released as energy.

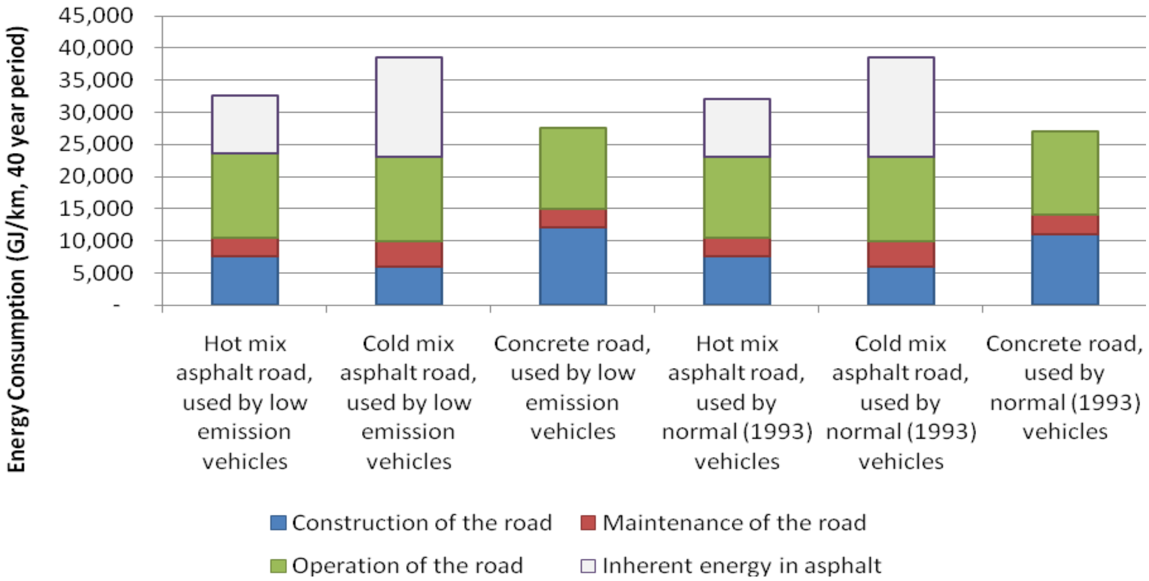


**Figure 3.5 Energy consumption for the road life cycle over a 40 year period**

The design phase was not considered in the Swedish IVL study. Subsequent assessment during this project has shown that, as the design period is relatively short and the materials used are relatively limited and small in quantity, the GHG emissions from the design stage are insignificant in comparison to construction, operation and maintenance. Design is therefore excluded from a GHG assessment completed using the Workbook, unless the project involves considerable international or interstate travel.

In the Swedish IVL study the final disposal of a road is considered to be maintenance of the road. Most roads have no final end. Instead they are reconstructed or replaced by a new road while the old road remains in operation.

The dominant energy consuming activity in the Swedish IVL study is the operation of the road, accounting for approximately half. Consumption of electricity by street lighting and traffic signals account for approximately 12 terajoules (TJ), which is nearly all of the energy consumed for the operation of the road.

As the emission factor for electricity consumption per GJ is 1.3-5 times greater than the emission factor for diesel (per GJ) it can be seen that, in Australia, it is likely that the GHG emissions generated by the operation of a road for any significant period of time will be equal to, if not greater than, the GHG emissions generated by the construction of the road and therefore operation of a road is considered significant and should be included in a GHG assessment.

It can be seen that maintenance activities are approximately 10-15% of the total energy consumption from construction, operation and maintenance activities. Whilst not as significant as construction and operation, maintenance is still considered material to a GHG assessment for a road project and is therefore included in the Workbook.

## 3.6 Materiality of construction activities

A range of Australian, New Zealand and international GHG assessments of road construction projects were reviewed in order to establish the significance (materiality) of emission sources during construction.

Table 3.1 provides details on the reference projects where the GHG assessment was completed using the RTA Construction Greenhouse Inventory Calculator (v1.5).

**Table 3.1 Summary of project details for reference projects**

| | Mickleham Road | Max Hill Pilot Project | Deer Park Bypass | Alpurt Motorway Extension |
|---|---|---|---|---|
| Project Description | Road duplication of existing | Road widening | Greenfield, two x two lane freeway | Four lane toll motorway |
| Location (Urban/Rural) | Urban, VIC | Urban, NSW | Semi-Urban, VIC | Urban, Auckland |
| Project value ($m) | $13.3 | $8.8 | $331.0 | |
| Project Duration (years) | | | 2 years, 2 months | |
| Road Length (km) | 2.4 | 1.0 | 9.3 | 7.5 |
| Pavement Width (m) | 7 | 14 | 22 | 14 |
| Number and type of structures | - | Cattle underpass | 10 bridges (including over passes), noise attenuation, 21 retained soil structure walls | 1 interchange, 2 bridges, 2 viaducts |
| Number of tunnels | - | - | - | 1 tunnel |

Table 3.2 shows the GHG emissions/m$^2$ of pavement for the reference projects listed in Table 3.1.

**Table 3.2 Comparison of GHG emissions per km for road construction projects**

| Emission Source | Units | Mickelham Road | Marx Hill Pilot Project | Deer Park Bypass | Alpurt Motorway Extension |
|---|---|---|---|---|---|
| **Liquid fuel combustion** | **t $CO_2$-e/m$^2$** | **0.027** | **0.061** | **0.063** | **0.251** |
| Plant & equipment | t $CO_2$-e/m$^2$ | 0.020 | 0.032 | 0.043 | 0.222 |
| Site vehicles | t $CO_2$-e/m$^2$ | 0.007 | 0.029 | 0.020 | 0.028 |
| **Electricity** | **t $CO_2$-e/ m$^2$** | **0.001** | **0.002** | **0.005** | **0.028** |
| **Materials** | **t $CO_2$-e/ m$^2$** | **0.150** | **0.089** | **0.208** | **0.298** |
| Cement | t $CO_2$-e/m$^2$ | 0.056 | 0.012 | 0.075 | 0.096 |
| Lime | t $CO_2$-e/m$^2$ | | 0.001 | | 0.078 |
| Steel | t $CO_2$-e/m$^2$ | 0.004 | 0.007 | 0.031 | 0.099 |
| Aggregate | t $CO_2$-e/m$^2$ | 0.040 | 0.055 | 0.024 | 0.019 |
| Hot mix asphalt processing energy | t $CO_2$-e/m$^2$ | 0.026 | | 0.027 | |
| Imported fill | t $CO_2$-e/m$^2$ | | | 0.023 | |
| Bitumen | t $CO_2$-e/m$^2$ | 0.018 | 0.012 | 0.020 | |
| Asphalt | t $CO_2$-e/m$^2$ | | | | 0.006 |
| Sand/Gravel | t $CO_2$-e/m$^2$ | 0.005 | 0.001 | 0.006 | |
| Fly ash | t $CO_2$-e/m$^2$ | 0.001 | | 0.001 | |
| Aluminium | t $CO_2$-e/m$^2$ | | 0.001 | | |
| Plastic | t $CO_2$-e/m$^2$ | | 0.0002 | | |
| Copper | t $CO_2$-e/m$^2$ | | | | |
| **Transport of materials** | **t $CO_2$-e/ m$^2$** | | **0.007** | | **0.003** |
| **Waste transport and disposal** | **t $CO_2$-e/ m$^2$** | | **0.003** | | **0.003** |
| **Vegetation removal** | **t $CO_2$-e/ m$^2$** | | **0.094** | | **0.071** |
| **Total** | **t $CO_2$-e/ m$^2$** | **0.178** | **0.256** | **0.275** | **0.653** |

Figure 3.63.6 shows the breakdown of GHG emissions for these road projects and several other international studies. More detailed breakdown graphs for each project are provided in Appendix B.

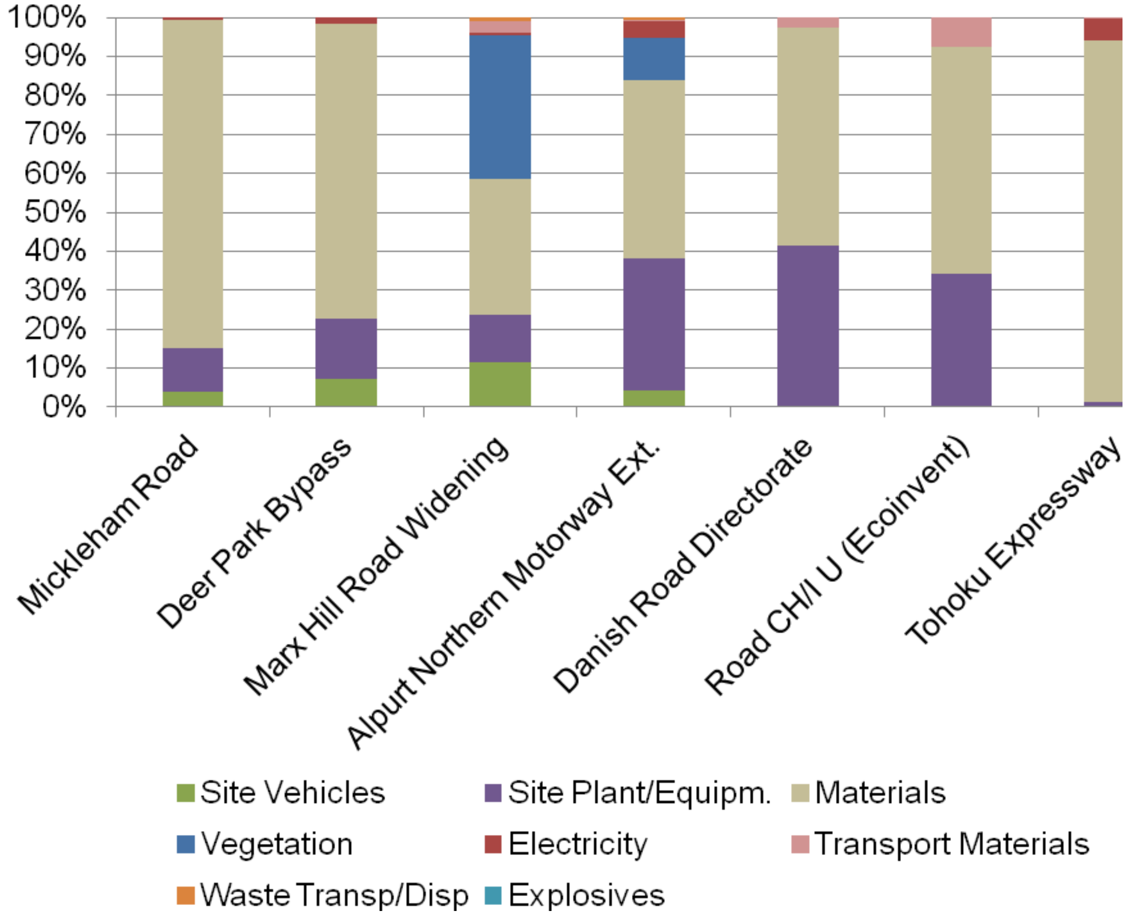


**Figure 3.6 Road construction – breakdown of emissions**

Figure 3.7 shows the contribution that the transport of materials makes over a range of transport distances. This data is presented for a range of construction GHG emissions per $m^2$ of pavement (0.1 t $CO_2$-e/$m^2$ – 0.7 t $CO_2$-e/$m^2$), which is consistent with the range of reference projects (Table 3.2). The following assumptions were made:

- All transport is by a 25 tonne articulated truck consuming 0.546 L diesel /km, based on data from the methodology.
- Empty return trips (i.e. effectively double transport distance)
- 1.467 tonnes of aggregate per $m^2$ of full depth asphalt road pavement, consisting of 0.372 t/$m^2$ in Asphalt, 0.430 t/$m^2$ in the Base course and 0.665 t/$m^2$ in the sub base.

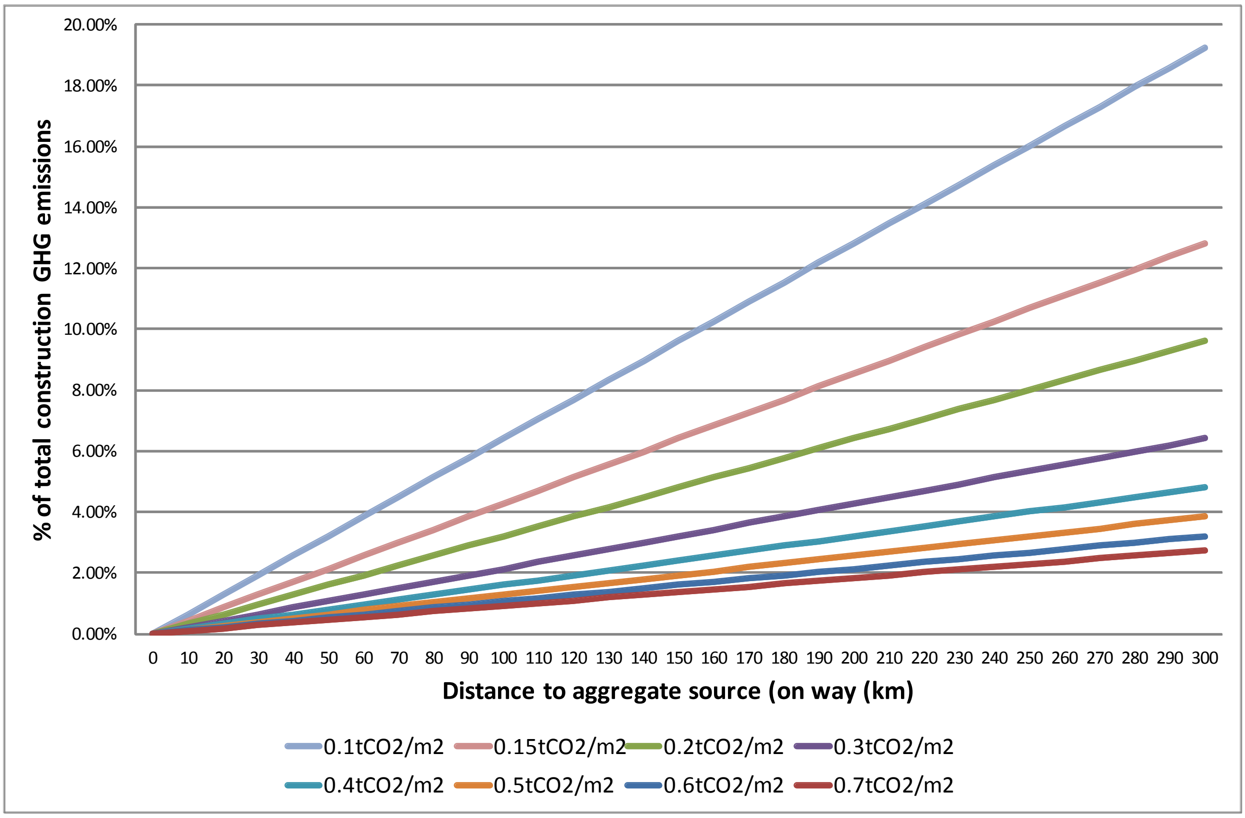


**Figure 3.7 Transport of aggregate percent contribution to construction GHG emissions**

It can also be seen in Figure 3.6 that the aspect of vegetation can be a significant impact in construction. Whilst, the methodology for determining the loss of sequestration through vegetation clearance is discussed in Section 4.1, the following is an assessment of it's materiality.

Given Australia's diversity of vegetation types and densities, two different scenarios were modelled. For the least significant of vegetation, in a lower biomass area as shown in Figure 3.8, the removal of sequestration becomes significant to construction somewhere between 0.8 and 4.6 hectares, depending on how large the projects footprint is.

However, if a more significant level of vegetation is used in a richer biomass area as shown in Figure 3.9 then the range at which the loss of sequestration becomes materially significant to construction somewhere between 0.2 and 0.8 hectares depending on how large the projects footprint is.

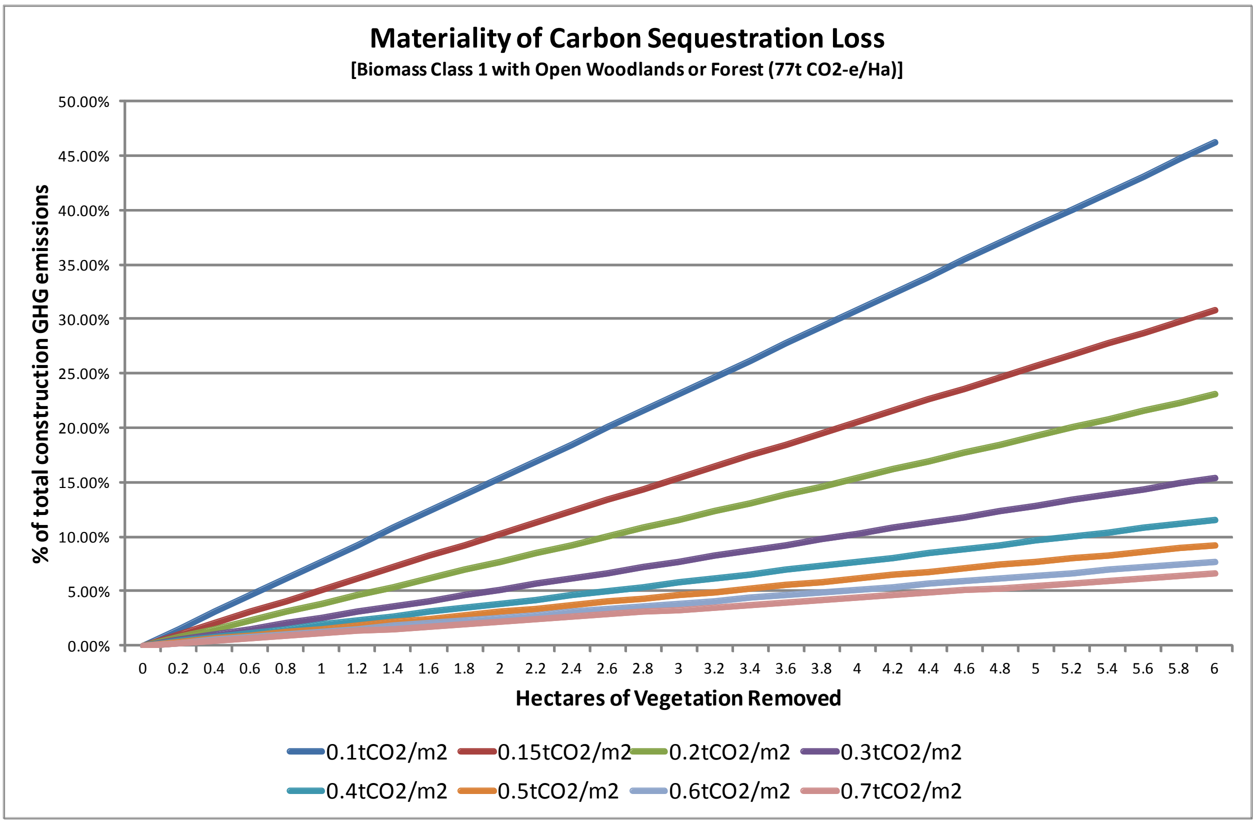


**Figure 3.8 – Loss of Sequestration for a low grade of vegetation**

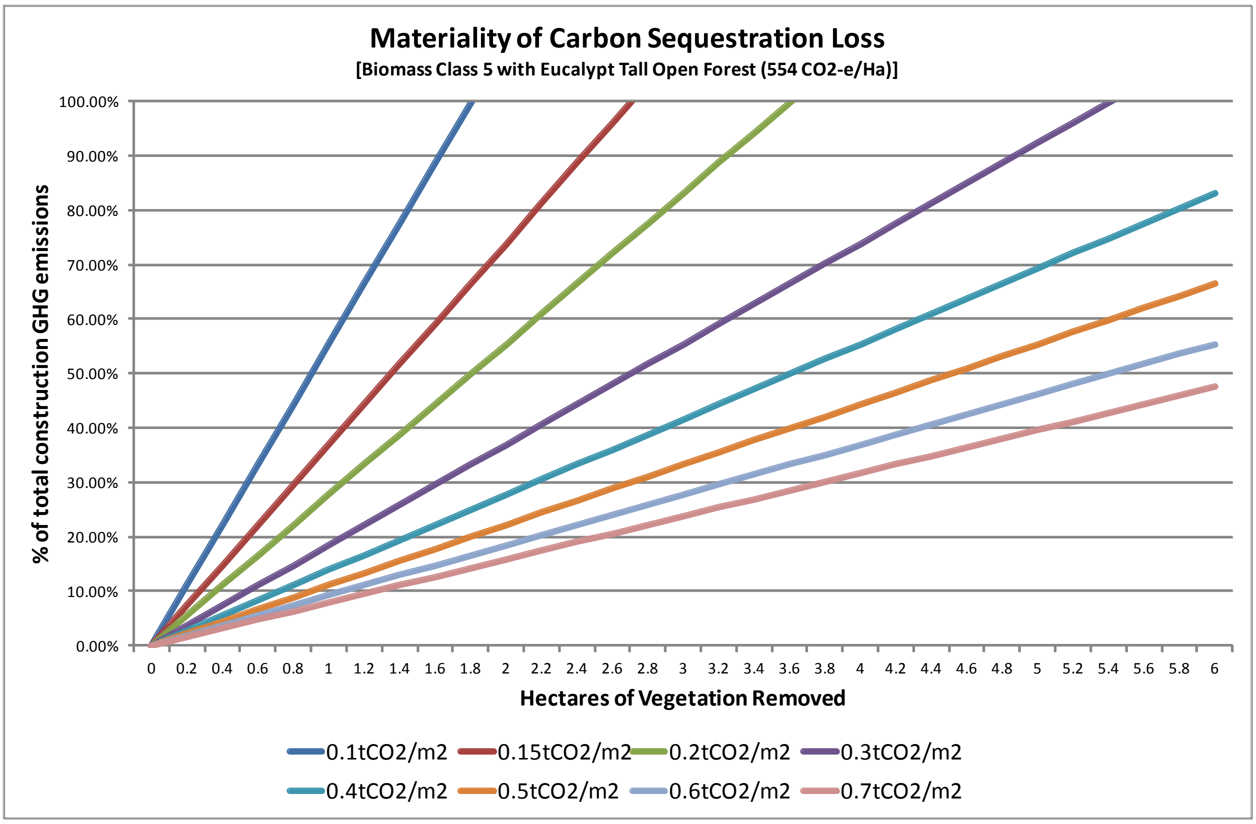


**Figure 3.9 – Loss of Sequestration for a significant grade of vegetation**

### 3.6.1 Findings

It can be seen from Table 3.2 as projects become more complex, and more structures are introduced, the GHG emissions per $m^2$ of pavement increases, which is expected. Table 3.2 also shows that there is considerable variance between projects for some emission sources including: site plant and equipment, steel, cement, lime, aggregates and vegetation removal. This variation is likely to be due to the variability in the road projects analysed and their differing components and designs.

The reference data shown in Table 3.2 and Figure 3.6 indicate that construction materials, combustion of liquid fuels and removal of vegetation are the major contributors to construction GHG emissions for road projects, accounting for 92 – 100% of all construction impacts.

It can be seen that embodied emissions in construction materials are dominated by cement, aggregates, bitumen, hot mix asphalt processing energy, steel and, in some instances, lime and imported fill. Plastic (e.g. pipes), copper, aluminium and fly ash contribute a negligible amount to the total GHG emissions for construction materials.

Figure 3.7 initially showed that for urban projects or projects with a high emission profile (i.e. road projects that include tunnels) the transport of materials is generally insignificant. However, if high volume materials, such as aggregates, are transported long distances (i.e. 200 km one way) then the associated emissions would be significant. The transport of materials should be included in the construction GHG assessment of projects that are long distances from construction materials. Subsequent analysis of twenty seven VicRoads projects identified that the average road greenhouse footprint was approximately 0.125 t $CO_2$-e/$m^2$. If a line was placed for this profile on Figure 3.7, then transportation would likely be significant at a one way distance of 50km. This has now been adopted as the transportation distance to ensure transport related emissions are more accurately estimated.

Vegetation removal contributes a large percentage of the construction GHG emissions for some projects and very little for others. Whether vegetation removal is significant will depend on the location of the project and the vegetation type and density and whether the vegetation has previously been disturbed. Based on the materiality assessment a figure of 0.5 hectares of vegetation removal will be adopted.

The reference projects indicated that the total **construction** GHG emissions may range from 0.15/$m^2$ to 0.7/$m^2$ of pavement. The following additional emissions sources have been assessed:

- Street lighting - assuming 12 steel street lamp posts/km of road (250W HPS lamps), 200kg of steel per lamp post and 4$m^3$ of concrete foundation per lamp post street lights would rarely contribute above 1% of the overall construction emissions.

- Road safety barriers – Steel: Assuming that no concrete footing is required[1] and approximately 23t of steel per km, steel road barriers can contribute up to 4% of the overall construction impact if the road is a dual carriageway and barriers are required on both sides of the carriageway in each direction. Concrete (F-type): Assuming that 70 m3 of concrete and 13t of steel is required per km, concrete road barriers can contribute up to 9% of the overall construction impact if the if the road is a dual carriageway and barriers are required on both sides of the carriageway in each direction.

[1] *http://www.ingalcivil.com.au/flexbeam.html*

- Large road signs (e.g. information signs) or regular smaller road signs (e.g. speed limit signs) - do not have a material contribution to construction projects. Even large information signs across highways (e.g. two 2mm x 5m x 6m aluminium sheets) supported on a steel frame would contribute less than 1% to the overall construction GHG emissions.

- Noise walls - Embodied GHG emissions in noise walls vary between approximately 13 kg $CO_2$-e/$m^2$ (plywood 28mm thick) to 64 kg $CO_2$-e/$m^2$ (steel sheet 3mm thick) including raw material, processing and transport impacts for a 14m road width. Consequently, 3m high noise walls on both sides of a 1km road, 4 lanes wide would contribute over 5% to the overall construction emissions when the entire length of the road is equipped with noise walls.

- Road marking as an activity - has an insignificant contribution to the overall construction emissions (<<1%) as identified in the paper, 'Lifecycle Assessment of a Road – A Pilot Study for Inventory Analysis', IVL, 2001.

- Detonation of explosives - have not been estimated in any of the reference cases, however it can be noted that it would require detonation of approximately 40 kgs of explosives per $m^2$ of road for explosives to contribute >5% of overall construction impacts, which would likely only be significant in longer tunnel projects or surface road projects with extensive cuts in hard rock (assuming 2.5kg of explosives per m3).

- Water consumption (approximately 26kL/year) and paper consumption (160kg/year or 64 reams of paper/year) per employee - contribute an insignificant amount to the GHG emissions during construction of a road project.

- Office waste - contributed 0.4% in the Alpurt Northern Motorway Extension (URS, 2008) and is unlikely to contribute significantly in any construction project (approximately 70kg per employee per year or <0.2 t $CO_2$-e per employee per year).

### 3.6.2 Conclusion

Materiality has been defined as where an emission source contributed more than 5% to the total GHG emissions for construction. Table 3.3 shows which emission sources are generally always significant, those that may be significant on a particular project and those that generally would be insignificant and excluded from an assessment.

The materials used to manufacture and install road barriers and noise walls should be captured in GHG assessments of urban road projects where they are used for more than 50% of the road's length on both sides.

Emissions relating to the transport of materials should only be included in GHG assessments of rural road projects that are located more than 50km from the materials source(s).

**Table 3.3 Summary of the materiality of construction emissions sources**

| Must be included | Inclusion project dependent | Can be excluded |
|---|---|---|
| **Scope 1 emission sources** | | |
| Combustion of fuel in Site Vehicles | Vegetation removal | Disposal of waste onsite |
| Combustion of fuel in Plant & Equipment | Combustion of fuel to power site offices<br>Detonation of explosives (tunnel projects or surface projects through hard rock only) | |
| **Scope 2 emission sources** | | |
| | Electricity consumption by plant and equipment | Electricity consumption by site offices |
| **Scope 3 emission sources** | | |
| Aggregate | Transport of materials | Transport and disposal of waste from site offices |
| Asphalt (Hot or Warm mix) | Transport of vegetation | Transport of employees & project related travel |
| Bitumen | Imported fill | Office consumables (e.g. paper consumption) |
| Cement | Lime | Transport and disposal of waste from demolition |
| Concrete | Construction of plant and equipment (if equipment is sacrificed) | Fuel combusted in hauling equipment to site |
| Steel including steel used in safety barriers and other road furniture | Noise walls | Road signs |
| Hot mix asphalt processing energy | | Copper |
| Sand (ingredient in concrete) | | Fly ash |
| Water (ingredient in concrete) | | Water used for dust suppression<br>Water consumption by site offices |
| | | Aluminium |
| | | Road marking |

## 3.7 Operation

The GHG emissions from the operation of a road typically relate to street lighting, traffic signals or intelligent transport systems (ITS).

Over a 50 year period, typical arterial roads and freeway ramps (250W HPS lamps) lighting would consume 640 kWh/m of road lit by street lighting (assuming that the lighting operates 12 hours a day and is spaced 86m apart). Assuming that lighting is on one sides of the carriageway and that the pavement is 20m wide this equates to 32 kWh/$m^2$ or 0.009-0.043 t $CO_2$-e/$m^2$ of pavement depending on the state/region that the project is in, and based on full scope emissions. This is between 7-34% of construction emissions for a project with total construction emissions of 0.125 t $CO_2$-e/$m^2$. Street lighting is therefore considered significant and should be included in a GHG assessment if a road has continuous street lighting on one side of the road for more than 15% of the road length in Victoria, 20% of the road length in the Australian Capital Territory, New South Wales, Queensland, Western Australia and the Northern Territory, 25% of the road length in South Australia, 80% of the road length in Tasmania and 100% of the road length in New Zealand.

Default quantity factors were developed for several types of road interchanges and intersections that involve traffic signals. Over a 50 year period, an intersection on an undivided road is estimated to consume 1,389,411 kWh if incandescent lighting is used or 247,201 kWh if LED lighting is used. This equates to 390 – 1,860 t $CO_2$-e for incandescent lighting, 147 – 705 t $CO_2$-e for Quartz Halogen Lighting and 70 – 330 t $CO_2$-e for LED lighting. For traffic signals to equate to 5% of construction emissions (taken to be 0.125 t $CO_2$-e/m$^2$), assuming that the road width is 20m, the signals would need to be **less than** 3.1 – 14.9km apart for incandescent lights, 1.2-5.6km apart for Quartz Halogen Lights or 0.5-2.65km apart for LED lighting. For an undivided arterial road using incandescent lighting, traffic signals are likely to be significant and should be included in a GHG assessment. If LED lights are used then traffic signals will only be significant if the signals are **less than** 0.6 km apart.

Intelligent Transport Systems are increasingly being used on freeways. However, little data currently exists regarding their typical electricity usage and hence a materiality assessment cannot be made on these systems at this time.

## 3.8 Maintenance

A review of maintenance data provided by the various road agencies highlighted that minor maintenance activities (i.e. planned and reactive maintenance) contribute less than 1% to the overall GHG emissions of a road over its entire life cycle. For example, the South Australian Department for Transport, Energy and Infrastructure uses approximately 274 kL/year of diesel to conduct minor maintenance (including inspections) on 6,555km of road. This equates to 0.042 kL/km or $2.1 \times 10^{-6}$ kL/m$^2$ (assuming that the average road pavement width is 20m wide). This would result GHG emissions of approximately $6 \times 10^{-6}$ t $CO_2$-e/m$^2$ of road or 0.003% of construction emissions. Even if the GHG emissions relating to material usage were to be included in the assessment of minor maintenance these activities would not be considered significant.

Figure 3.5 shows that the GHG emissions for maintenance activities are approximately 10-15% of the total GHG emissions from construction, operation and maintenance activities. As minor maintenance activities contribute much less than 1% to total GHG emissions it can be assumed that the GHG emissions associated with major maintenance (e.g. road rehabilitation) account for practically 100% of this 10-15% and major maintenance is therefore considered a significant activity and should be included in a GHG assessment of a road project.

# 4. Default quantity factors

The Workbook provides an alternative method for determining quantities used for various activities/emission sources, should actual data not be available or readily accessible. The alternative method uses an indicator of activity level and default quantity factors to estimate the quantities.

The following section provides a brief introduction to the data sources used in determining the default quantity factors.

## 4.1 Vegetation clearance

The default quantity factors for vegetation clearing are intended to estimate the loss of $CO_2$ sequestration potential through the removal of 1 hectare of the specified vegetation. However, it is always preferable to use relevant local data achieved through flora studies.

### 4.1.1 Australia

The initial version of the workbook contained a loss of sequestration methodology modelled on its relationship with rainfall and the level of vegetation disturbance. Subsequent investigation has shown that whilst it is a valid methodology for most of Australia, it was not suitable for all of Australia.

Consequently, another methodology has been developed. The relevant supporting document is shown in Appendix C.

**NOTE:** The default quantity factor method used for vegetation clearance in the Workbook does not take into account the complex nature of eco-systems. This method should not be used for purposes outside those intended by the Workbook.

### 4.1.2 New Zealand

The vegetation clearance methodology for New Zealand is currently under review. It is planned to add the new methodology to the workbook once it has been finalised. For further information contact NZTA.

### 4.1.3 Revegetation

FullCAM was used initially to model the impact of revegetation on a site. The results of the modelling are shown in Figures 4.1 and 4.2. It can be seen that the correlation between $CO_2$ sequestered following revegetation is not well correlated with average annual rainfall. As the GHG benefits of revegetation cannot be accurately estimated using a simple relationship with rainfall the benefits of revegetation have been excluded from the Workbook assessment methodology.

It is acknowledged that work is occurring in this area such as the Australian Federal Government's Carbon Farming Initiative, which may provide a better basis for determining the materiality of revegetation. This work will be used to inform subsequent revisions of the workbook methodology. However, until this time it is still assumed that revegetation is not materially significant.

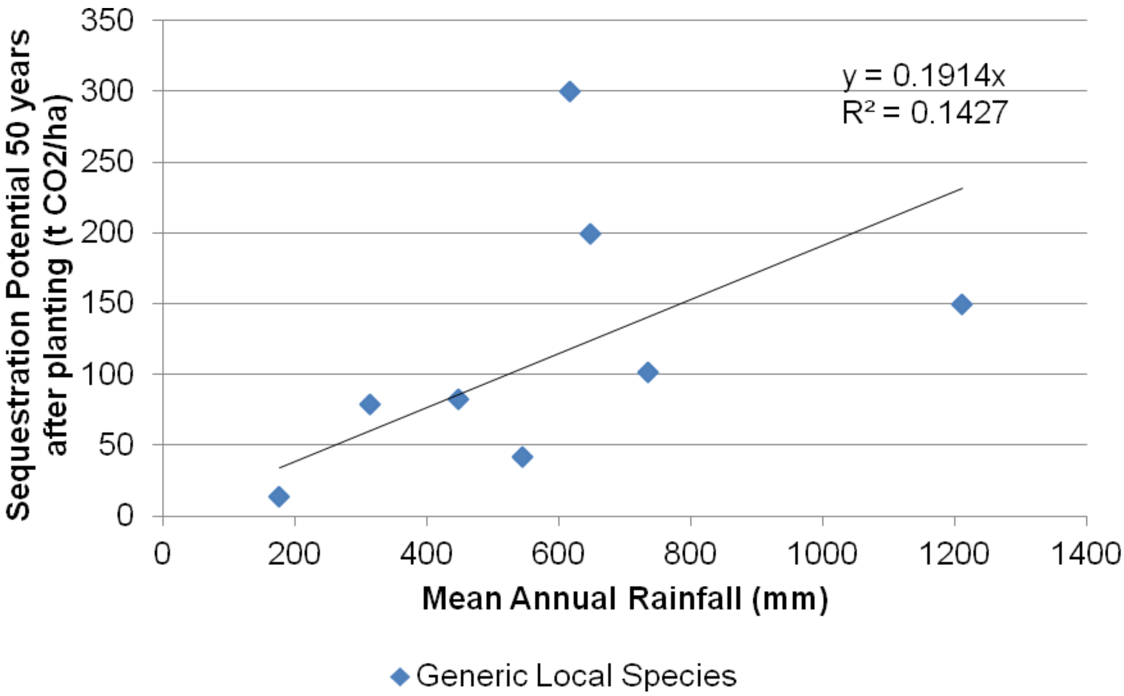


**Figure 4.1 Carbon dioxide gained from revegetation – raw data**

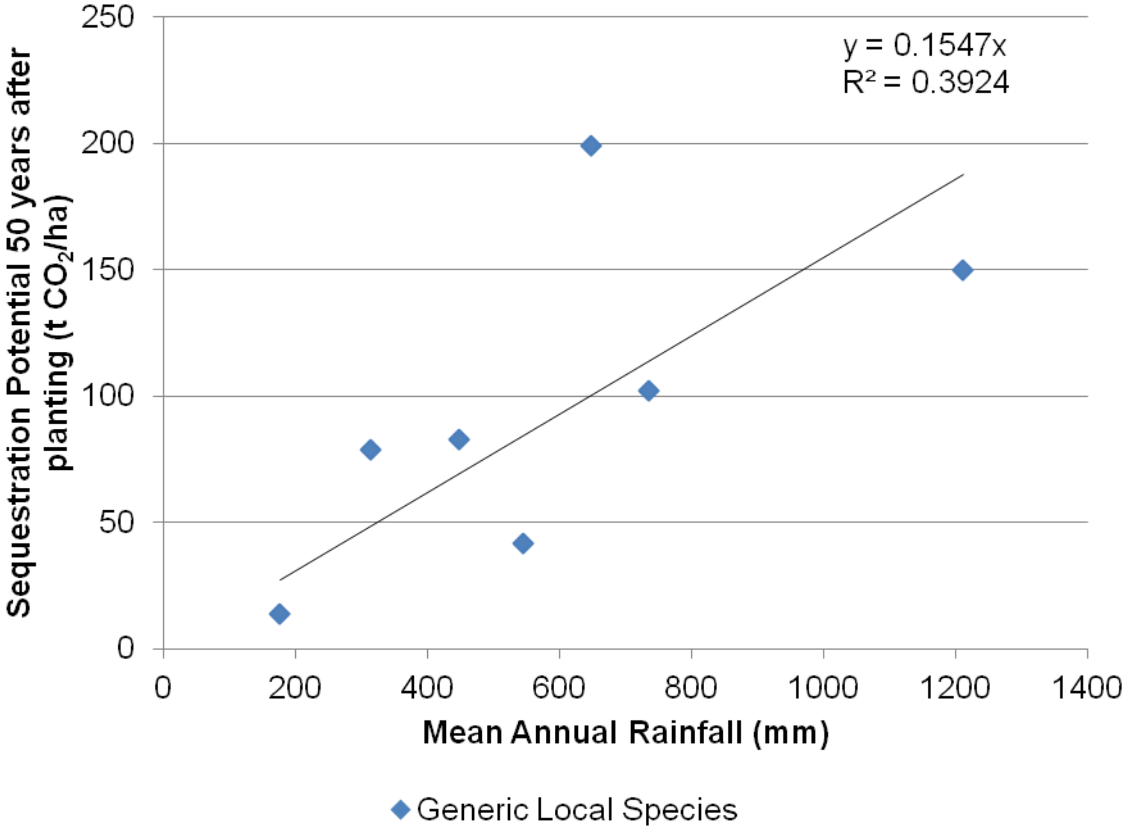


**Figure 4.2 Carbon dioxide gained from revegetation – with Hobart data removed**

## 4.2 Pavement types

Default quantity factors have been developed based on an abridged version of the New South Wales Road Transport Authority (RTA) pavement types. The pavement types selected were considered to be those that predominate in Australian and New Zealand road design. The materials used and depth of materials for each pavement type is shown in Figure 4.3.

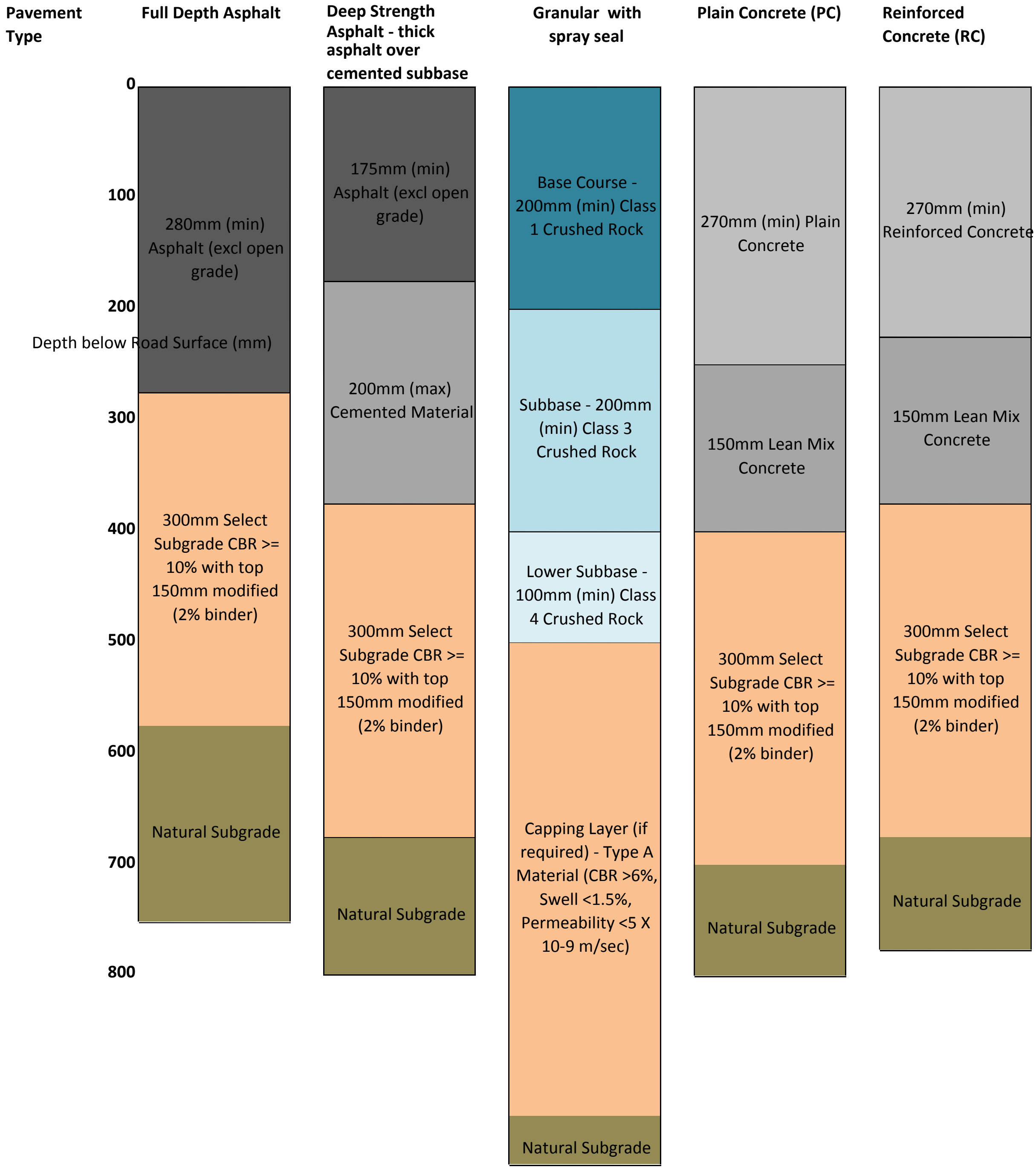


**Figure 4.3 Pavement types and material depths**

### 4.2.1 Warm Mix Asphalt Factor

Warm mix asphalt (WMA) is a road construction material seen as having benefits including greenhouse benefits, when compared to traditional Hot Mix Asphalt.
Given the number of technologies available, there exists no agreed embodied carbon value for WMA. Following a review of literature, the following is a factor which has been derived, in order to allow the inclusion of WMA within the methodology.

Derivation of WMA Factor based on greenhouse gas calculator, accessed on the US National Asphalt Pavement Association website, where within the supporting documentation[2], it was stated an energy reduction of 1000 BTU/t$^o$F

A recent field trial in Victoria[3] showed an average reduction of 29$^o$C (84.2$^o$F), therefore it is 84,200 BTU/t decrease in energy for a decrease of 29$^o$C. The conversion from BTU to GJ results in 0.089 GJ/t. Under the assumption that the reduction in energy comes from primarily a reduction in gas consumption, the National Greenhouse Account factors 2012[4], have a conversion factor of 51.33 kg CO2-e/GJ.

Results in 4.57 kg$CO_2$-e/t decrease from HMA to WMA for a 29$^o$C decrease in heating temperature. Given that the current HMA factor is 60 kg $CO_2$-e/t, this is a decrease of approximately 7.6%.

This is in the same order of magnitude as the Rippol and Farre article Evaluation of Greenhouse Gas Emissions from the Production of Hot Asphalt Mixtures[5] . Their numbers were a 5.7% decrease for a 25$^o$C decrease and an 8.0% decrease for a 35$^o$C.

Therefore, in the absence of an agreed factor for WMA and the variety of WMA technologies, a 7% decrease will be adopted to enable the calculation of a WMA pavement to be calculated. However, this number will be adjusted once agreed Australian WMA factor(s) are determined.
This results in a factor for WMA of 55.8 kg $CO_2$-e/t or 0.0056 t$CO_2$-e/t.

[2] *http://www.asphaltpavement.org/ghgc/GHGC%20v4%20instructions.pdf*
[3] *Austroads, Field Validation of Warm Mix Asphalts, Report AP-T214-12, p11*
[4] *http://www.climatechange.gov.au/~/media/publications/nga/NGA-Factors-20120829-PDF.pdf, Accessed 10/02/2013*
[5] *Rippol, JO & Farre, CM 2008, 'Evaluation of greenhouse gas emissions from the production of hot asphalt mixtures', Eurasphalt and Eurobitume Congress, 4th 2008, Copenhagen, Denmark, Eurasphalt & Eurobitume Congress Secretatiat, Brussels, belgium, 10pp.*

## 4.3 Default quantity factor data sources

### 4.3.1 SA DTEI Greenhouse gas assessment tool

The South Australian Department of Transport, Energy and Infrastructure (SA DTEI) has developed a Greenhouse Gas Assessment Tool (GGAT) for use by cost estimators. It provides default quantity factors for the majority of the road elements. Data from this tool has been used where possible to develop default quantity factors for demolition and earthworks, drainage and structures.

### 4.3.2 Other data sources

Where default quantity factors have not been defined in the DTEI GGAT they have been developed by PB Transport Engineers, road project cost estimators or road agencies specifically for this project.

# 5. Emission factors

Emission factors are commonly used to convert the quantity of material, fuel, waste and other sources used to the corresponding quantity of GHG emissions associated with the use of that source. Emission factors for Scope 1 and Scope 2 emissions are commonly available for most regions/countries. However, Scope 3 emissions are more location and process specific. Refer to Section 2.3.1 of the Workbook for an explanation of emission scopes.

The following section provides a summary of how the Scope 3 emission factors were estimated and the emission data sources used in the development of the Workbook.

## 5.1 Approach used to develop emission factors for materials

Different industrial sectors have traditionally used different approaches to estimating emission factors for materials and this can lead to incompatible data. One of the key aspects of concern is the approach taken to allocate the GHG impacts from a process where several products are manufactured from the same process.

A single uniform allocation method, the economic method, has been adopted to develop the emission factors for the GHG assessment Workbook. This method allocates the burdens from a process in proportion to the value of the products/co-products generated. This is a different approach taken to the traditional method of allocation for the following materials:

- oil refinery products are traditionally allocated on a calorific content basis (which is common in this sector). Using the economic allocation method transfers a significant proportion of the GHG burden from the relatively low value products (e.g. bitumen) onto premium value products (e.g. premium petrol).
- fly ash from coal fired power stations traditionally has no GHG burden from coal mining, processing and combustion activities. The use of economic allocation provides proportional GHG burden to fly ash based on the average medium term market price for the electricity generated and the fly ash produced.

This allocation adjustment only affects the emission factors for materials (scope 3) and does not change the factors sourced from the DCCEE's NGA Factors and the NZ MfE's Emission Factors and Methods.

## 5.2 Summary of available data sources

Different data sources are suitable for different locations as varying electricity and fuel mixes may be used in any given location. For example, steel produced in Australia has roughly 15% more embodied GHG emissions in comparison to steel produced in New Zealand due to the difference in the GHG burden of the electricity supplies in these regions (SimaPro in Australia, 2010).

The following section provides a summary of the data sources currently available in Australia, New Zealand and internationally. Where available, emission factors have been taken from the most recent Australian and New Zealand government accounts reports (NGA Factors Workbook and Emissions and Methods Workbook respectively). The most relevant data sources have been prioritised in Section 5.3.

### 5.2.1 Australian data sources

#### 5.2.1.1 DCCEE National Greenhouse Accounts Factors Workbook

The National Greenhouse Accounts (NGA) Factors Workbook has been prepared by the Department of Climate Change and Energy Efficiency (DCCEE). It is designed for use by companies and individuals to estimate GHG emissions for reporting under various government programs and for their own purposes. The DCCEE NGA factors Workbook provides emission factors ranging for energy, fuel, waste and agriculture emission sources, which are recognised as the most well represented for Australia (DCCEE, 2010).

#### 5.2.1.2 SimaPro and the Australian LCA Dataset

The Australian LCA Dataset used by the SimaPro software has been developed from 1998 up to 2004 by the RMIT Centre for Design. The data was originally developed with the Cooperative Research Centre (CRC) for Waste Management and Pollution Control, as part of an Australian Inventory data project. The data from this project has been progressively updated, particularly the data for metals production, energy, transport and paper and board production. New data has been added for waste management from: EcoReycle projects in Victoria, agricultural inputs and a comparison of transport fuels undertaken for the Australian Greenhouse Office and data on copper from published work from CSIRO (Terry Norgate). Uncertainty data is progressively being added to the database. This is currently limited to data for fuels, electricity steel and aluminium data (SimaPro in Australia, 2010).

#### 5.2.1.3 FullCAM and National Carbon Accounting System

The FullCAM model was developed as part of Australia's National Carbon Accounting System (NCAS) to track the GHG emissions and carbon stock changes associated with land use management. FullCAM is a fully integrated carbon accounting model for estimating and predicting all biomass, litter and soil carbon pools in forest and agricultural systems. In addition to this, it accounts for changes in major GHG, nitrogen cycling and human-induced land use practices. The model is extensive, but it can be used to generate common factors that are easy to apply (AGO, 2005).

#### 5.2.1.4 Australian life cycle (AusLCI) database[6]

The Australian life cycle inventory database (AusLCI) is currently being developed by the Australian Life Cycle Assessment Society (ALCAS) to provide national, publicly accessible and transparent life cycle inventory (LCI) data on a wide range of Australian products and services. There is no data currently available. The project will be releasing its first range of data as part of the BPIC/ICIP project in November 2010, which will provide Australian LCI data on Australian building products (ALCAS, 2009).

#### 5.2.1.5 Australian Building Products Innovation Council (BPIC)[7] and Industry Cooperative Innovation Programme (ICIP)

The Australian Building Products Innovation Council (BPIC) and the Federal Government's Industry Cooperative Innovation Programme (ICIP) are currently developing an extensive database of LCI data for major Australian building products and construction materials. The data will be released in November 2010 as the first contributing industry sector of the AusLCI

[6] *See: www.auslci.com.au/*
[7] *See: http://www.bpic.asn.au/LCIMethodology.htm*

initiative. The database will provide industry-certified baseline figures for the whole of life environmental performance of every common building material in Australia (BPIC, 2009).

## 5.2.2 New Zealand data sources

### 5.2.2.1 NZ MfE Emission Factors and Methods Workbook

The New Zealand Ministry for the Environment provided a list of default emission factors in its Emission Factors and Methods Workbook, 2008. Emission factors were developed in accordance with ISO 14064-1 and GHG Protocol requirements. The majority of the information used in developing the factors is drawn from New Zealand government agencies. The data covers emissions factors for energy, transport, major appliances and waste to landfill (MfE, 2008).

### 5.2.2.2 Ecoinvent NZ

The Ecoinvent New Zealand database is Ecoinvent v2.2 data that has been adapted to New Zealand's context. The main difference in this adjustment is that the electricity fuel mix has been tailored to New Zealand's electricity and fuel supply and the inputs from the technosphere have also been adjusted with New Zealand parameters. Data is included for the: energy; transport; building materials; chemicals; pulp and paper; waste treatment and agricultural sector (Swiss Centre for Life Cycle Inventories, 2010.

### 5.2.2.3 Centre for Building Performance Research (CBPR)

The Centre for Building Performance Research (CBPR) at Victoria University in Wellington, New Zealand has produced data on the emission factors for New Zealand building materials in a report titled, "Embodied Energy and $CO_2$ Coefficients for New Zealand Building Materials". The report was released in March 2003 and has been recognised as an appropriate source for New Zealand, where data is not available from the New Zealand Emissions and Methods Workbook (Alcorn, 2003).

### 5.2.2.4 NZ MAF Permanent Forest Sinks Initiative (PFSI)

The Permanent Forest Sinks Initiative (PFSI) has produced a carbon assessment methodology in July 2007 for the New Zealand Ministry of Agriculture and Forestry (MAF). The outcome has provided a wide range of emission factors for New Zealand vegetation, which has been recognised as the best source of emission factors for vegetation clearance in New Zealand (PFSI, 2007).

## 5.2.3 International data sources

### 5.2.3.1 Inventory of Carbon and Energy (ICE), UK

The Inventory of Carbon and Energy (ICE) is the United Kingdom's University of Bath's embodied energy and embodied carbon database. The inventory consists of embodied energy and carbon coefficients for building materials. The database stores relevant information from an extensive collection of data sources (i.e. journal articles, Life Cycle Assessments (LCA's), books, conference papers, etc.) (University of Bath, 2007)

## 5.3 Priority of data sources - Australia

The emission factor data sources discussed above have been prioritised in terms of their applicability to road projects in Australia. Should new emission factors need to be developed the data sources should be used in the order shown below.

### 5.3.1 Energy consumption

1. DCCEE National Greenhouse Accounts (NGA) Factors Workbook
2. AusLCI database (Upon release)
3. SimaPro and the Australian dataset

### 5.3.2 Vegetation clearance

1. FullCAM model for specific location
2. DCCEE National Greenhouse Accounts (NGA) Factors Workbook
3. Inventory of Carbon and Energy (ICE), UK

### 5.3.3 Materials (concrete, steel, etc)

1. Building Products Innovation Council database (BPIC/ICIP) (Upon Release)
2. AusLCI database (Upon Release)
3. SimaPro and the Australian dataset
4. Other data sources

## 5.4 Priority of data sources - New Zealand

The emission factor data sources discussed above have been prioritised in terms of their applicability to road projects in Australia. Should new emission factors need to be developed the data sources should be used in the order shown below.

### 5.4.1 Energy consumption

1. NZ MfE Emission Factors and Methods Workbook
2. Centre for Building Performance Research (CBPR)
3. Ecoinvent New Zealand database

### 5.4.2 Vegetation clearance

1. MAF Permanent Forest Sinks Initiative (PFSI)
2. FullCAM model for a specific location
3. Inventory of Carbon and Energy (ICE), UK

### 5.4.3 Materials (concrete, steel, etc)

1. Centre for Building Performance Research (CBPR)
2. Ecoinvent New Zealand database
3. SimaPro and the Australian dataset

# 6. Time period for operation and maintenance assessments

The operation and maintenance GHG emissions have been estimated for a 50 year time period. A 50 year time period was selected for several reasons:

- It is the common design life of rigid pavements and is greater than the common design life of flexible pavements (30 years)
- The knowledge of maintenance regimes over this period is relatively well known
- It is approximately the time for which we have been using rigid and flexible pavements
- It is not such a long period that the contribution from operation and/or maintenance outweighs the contribution of construction.
- It is sufficient time for the majority of vegetation to reach its full carbon sequestration potential

Whilst 100 years is the time period used more typically in life cycle assessments and is the design life for structures such as bridges 50 years was found to be the optimum time period when considering the factors outlined above.

# 7. Updating the Workbook

The following tasks will be undertaken annually to update the Workbook.

1. **New materials or processes** – Review and confirm any proposed materials or process additions for the Workbook (e.g. emission factors for asphalt with RAP, warm mix asphalt, revegetation)

2. **Update of emission factors** – If, within the previous twelve month period, the data sources used in develop the emission factors are revised or if a new data source is published that has superior emissions data (e.g. a source that uses local data as opposed to international data) then the emission factors will be revised to take into account these changes.

3. **Update default quantity factors** – Review GHG assessments that have been completed at a project's various delivery phases (e.g. scoping, development, delivery) to assess the level of variance between a project's assessment that used mostly default quantity factors and an assessment that use mostly actual usage data. These reviews will be used to refine default quantity factors and better understand the accuracy levels that can be placed on them.

4. **Update of materiality assessments** – Review GHG assessments that have been completed to determine whether the materiality assessment is appropriate. Where possible, some GHG assessments should include items that have been excluded or are borderline (e.g. electricity consumption, waste, transport of materials) to ensure that original assumptions.

5. **Update Workbook and Supporting Document text** – TAGG to issue a feedback form or hold informal interviews with new users of the Workbook/Supporting Document to establish any sections that result in confusion or are unclear and need revision. This may include outputs from the use of the Workbook and Supporting tools. Revisions will be agreed with TAGG as appropriate.

6. Address any other issues which have arisen through the use of the Workbook, such as feedback or queries from third parties.

## 7.1 Have a query or want to provide feedback?

Below is a list of TAGG members who were involved in the development of this Workbook. Should you have any queries regarding the methodology presented in the Workbook or to provide your comments on the Workbook and/or Supporting Document they are a point of contact.

| Name | Agency | Email address |
|---|---|---|
| Vanessa Browne | NZTA, NZ | Vanessa Browne@nzta.govt.nz |
| Anne Welsh, Andrew Larwood | DPTI, SA | Anne.Welsh@sa.gov.au |
| Con Lambrous | RMS, NSW | Con.Lambous@rms.nsw.gov.au |
| Louis Bettini | Main Roads, WA | louis.bettini@mainroads.wa.gov.au |
| Dick Shaw | DIER, Tas | Dick.Shaw@dier.tas.gov.au |
| Simon Renton | VicRoads, Vic | Simon.Renton@roads.vic.gov.au |

# 8. References

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# Appendix A

Emission sources considered when developing GHG Assessment Boundaries

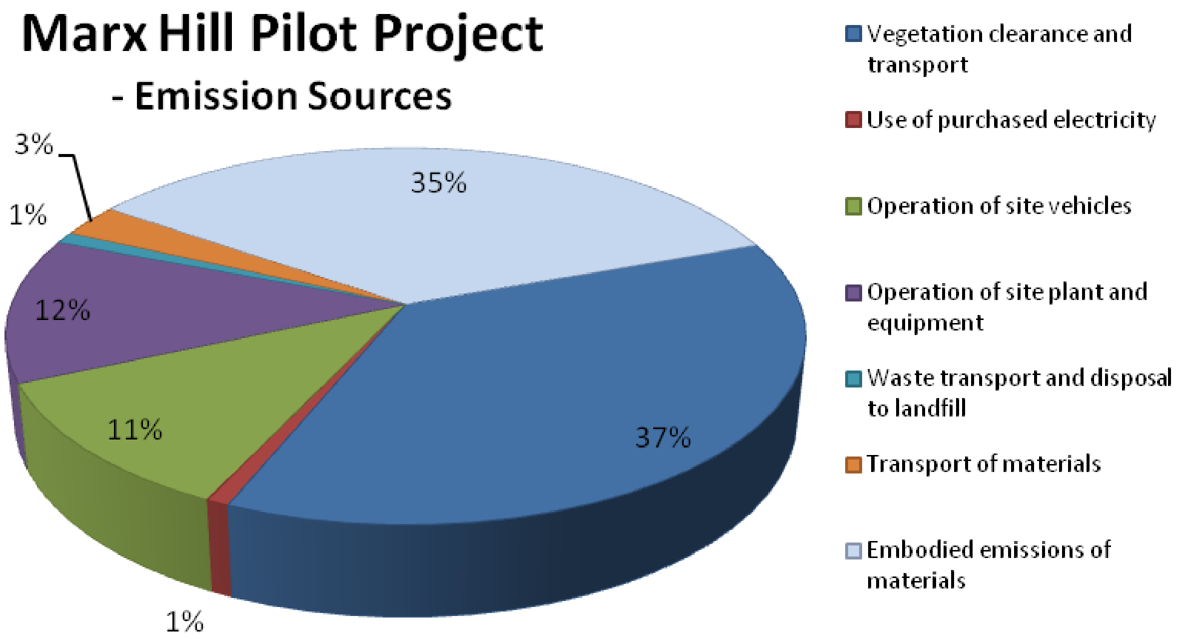
When setting the **Assessment Boundary**, several life cycle stages, unit processes and flows have been taken into consideration including:

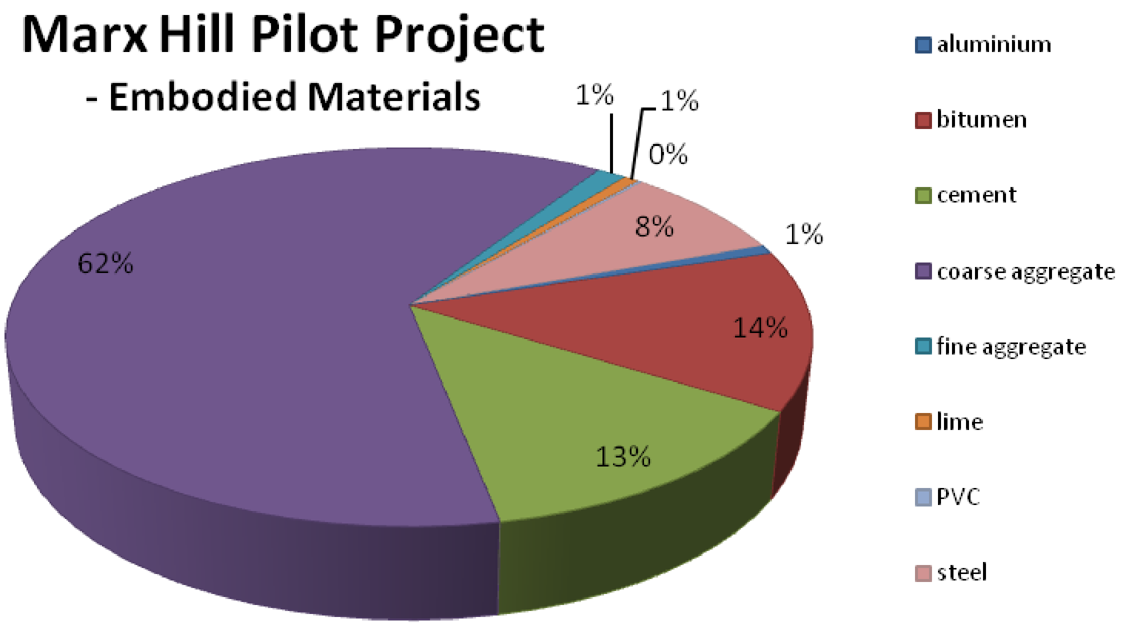
1. Extraction, production and transport of purchased fuels
2. Mining, production and transport of purchased materials or goods
3. Disposal of waste generated in the production of purchased fuels, materials and goods
4. Growth and regrowth of biomass products or energy sources
5. Transport of people including project related travel
    a) this is usually excluded from the scope of manufacturing processes to produce products, but might be an important consideration in the planning of transport infrastructure
6. Pollution control processes that are not an integral part of the industrial processes under study (e.g., contaminated land)
7. Construction and maintenance of plant, vehicles, and machinery used for any phase of a road project
8. Use phase of products and services (e.g. operation and maintenance of the road)
9. Disposal of waste generated by the project including through incineration, recovery of waste materials, and recycling and other end-of-life processes.
10. Outsourced activities (e.g. maintenance of equipment, activities undertaken by sub-contractors)
11. Cost of equipment, consumables, repairs, maintenance and communications relating to a building lease
12. Use of paper in the course of a project

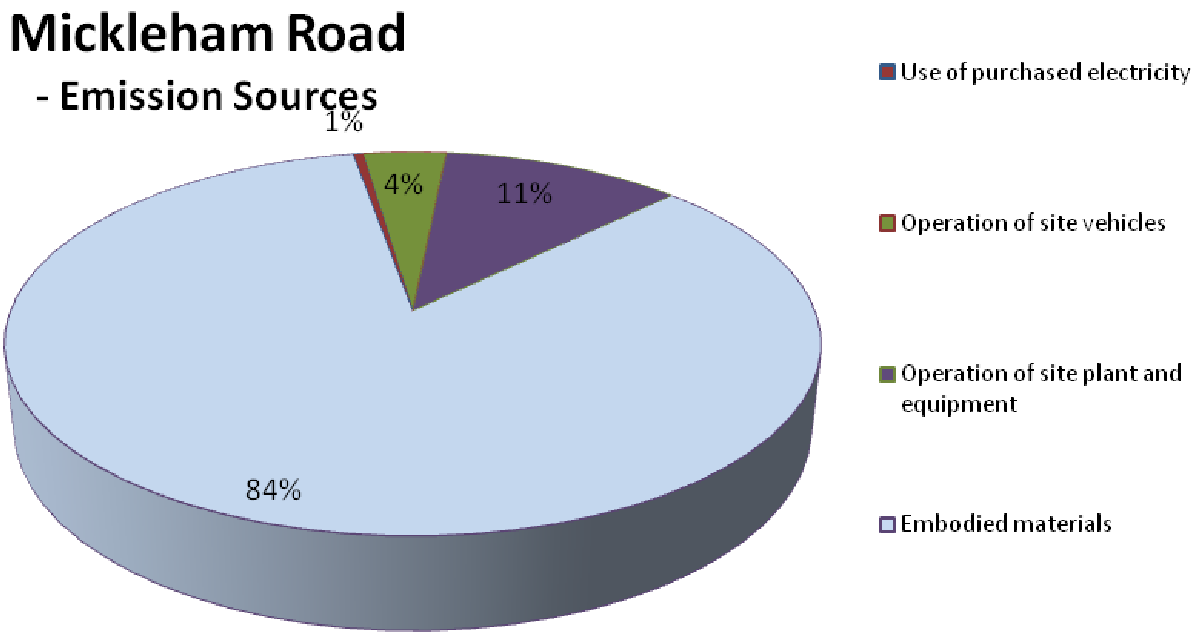
Items 1–5 and 8-10 have been included within the GHG Assessment Boundaries.

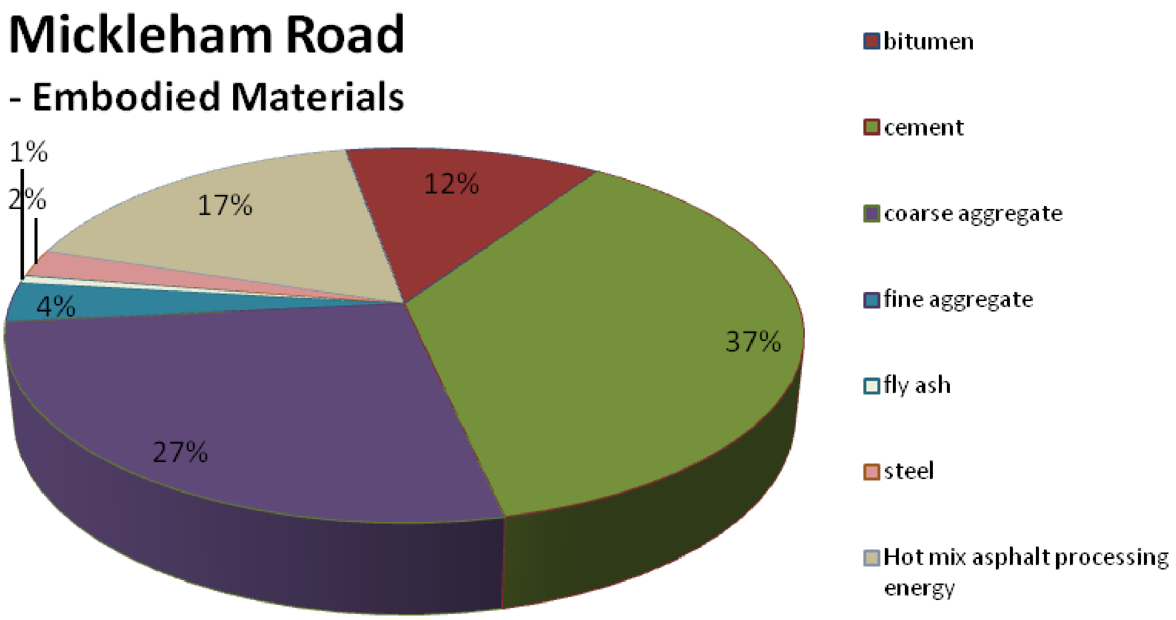
# Appendix B

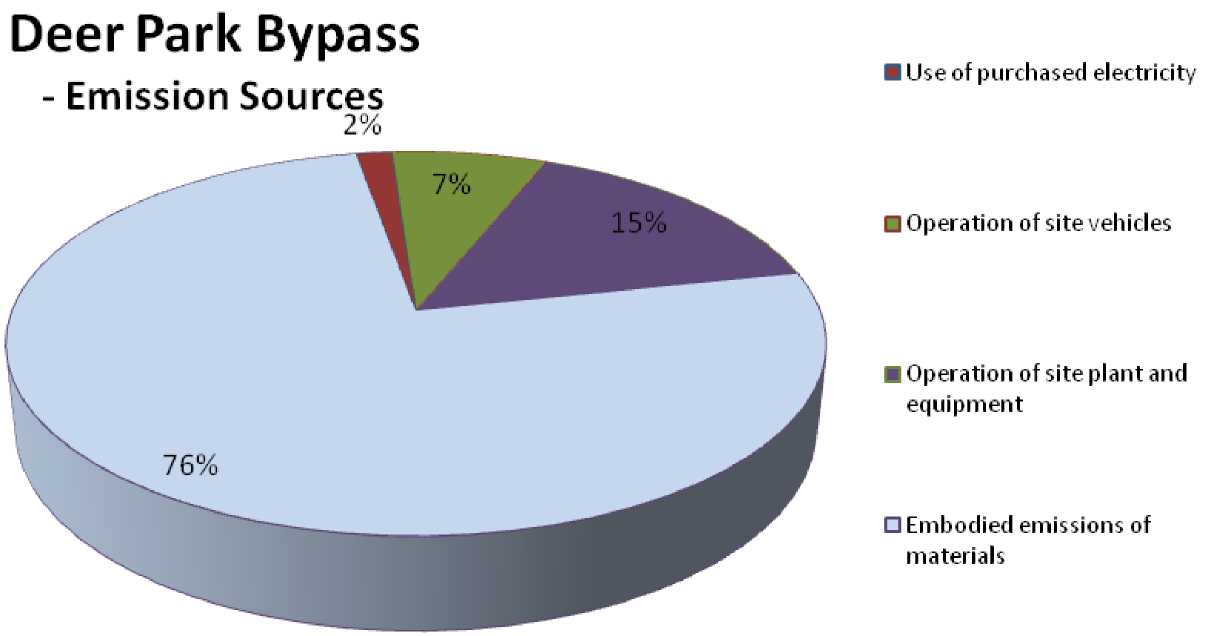
Supporting information - Construction materiality assessment graphs


Marx Hill Pilot Project
- Emission Sources
3%
1%
35%
12%
11%
37%
1%
Vegetation clearance and transport
Use of purchased electricity
Operation of site vehicles
Operation of site plant and equipment
Waste transport and disposal to landfill
Transport of materials
Embodied emissions of materials

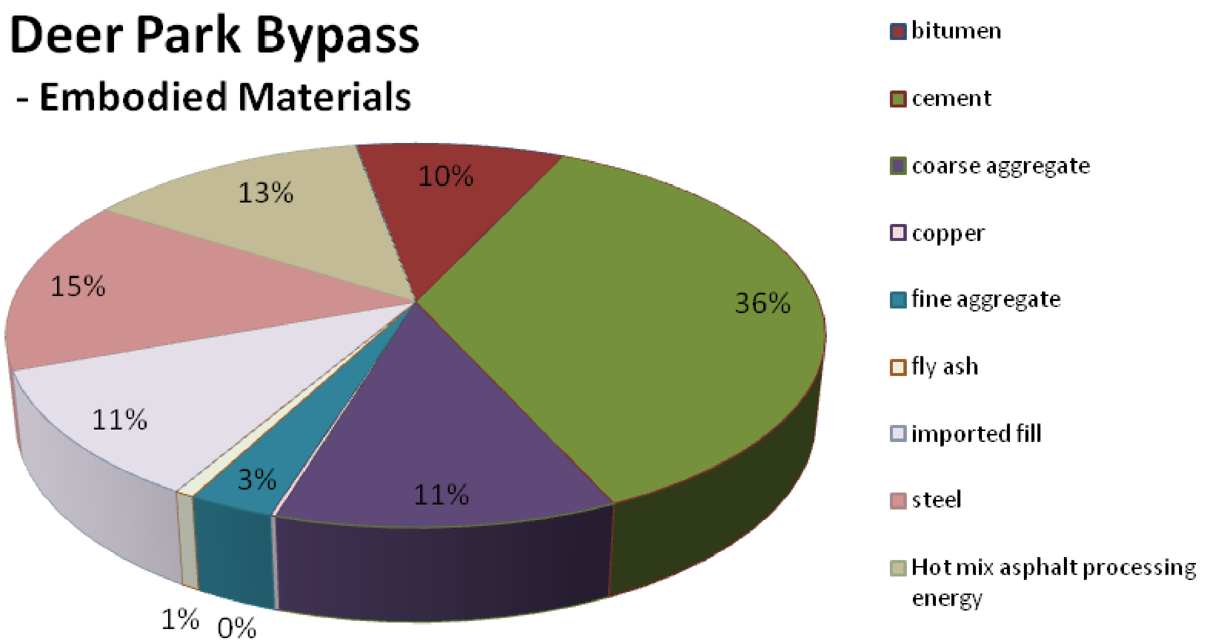

Marx Hill Pilot Project
- Embodied Materials
1%
1%
0%
8%
1%
62%
14%
13%
aluminium
bitumen
cement
coarse aggregate
fine aggregate
lime
PVC
steel


Mickleham Road
- Emission Sources
1%
4%
11%
84%
Use of purchased electricity
Operation of site vehicles
Operation of site plant and equipment
Embodied materials

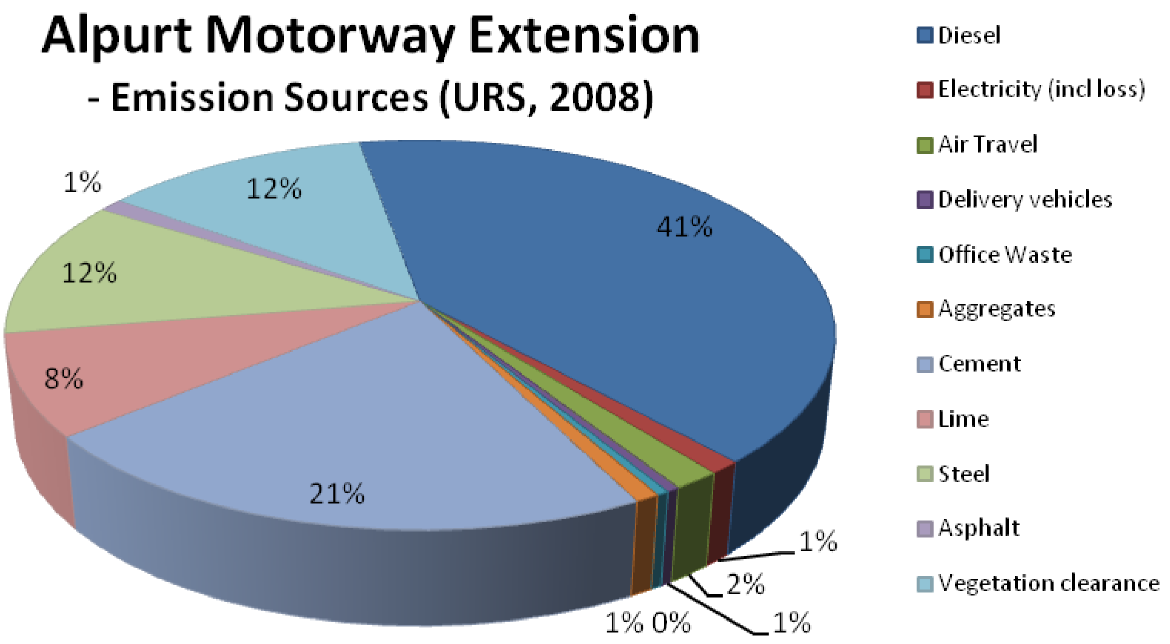

Mickleham Road
- Embodied Materials
1%
2%
17%
12%
4%
37%
27%
bitumen
cement
coarse aggregate
fine aggregate
fly ash
steel
Hot mix asphalt processing energy

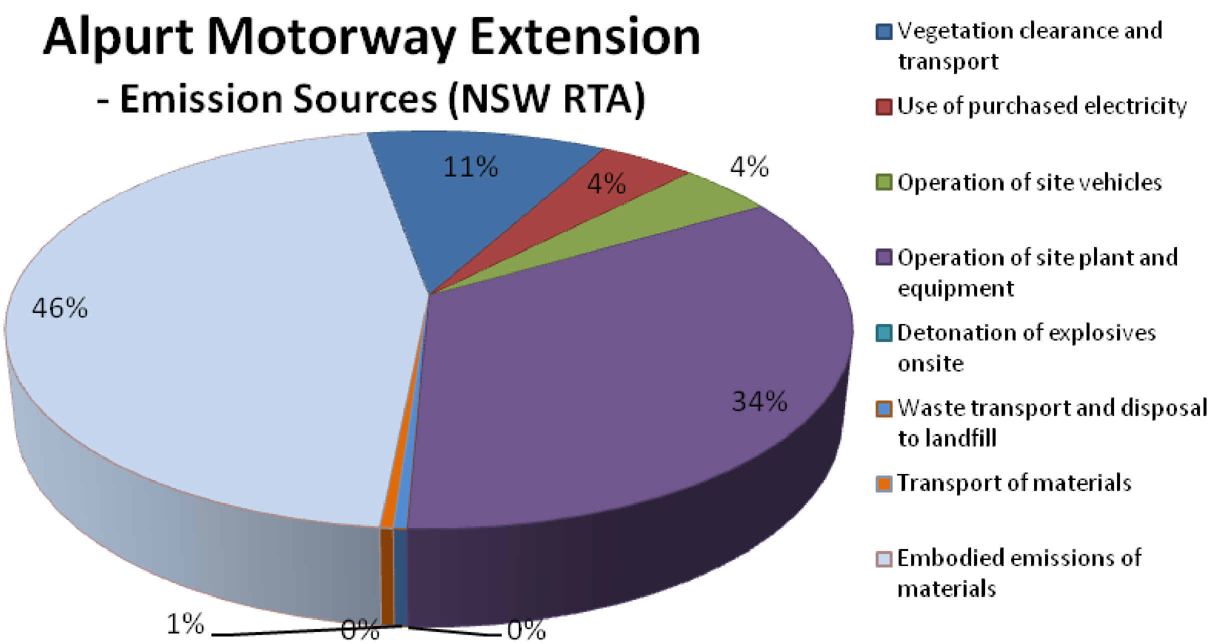


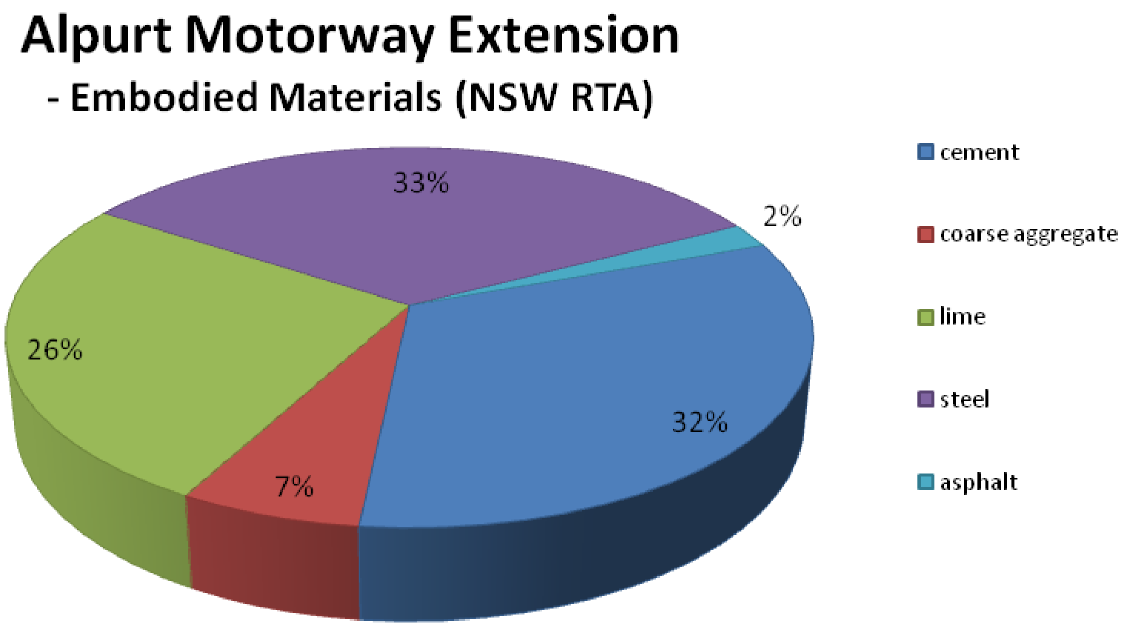
Deer Park Bypass
- Emission Sources
2%
7%
15%
76%
Use of purchased electricity
Operation of site vehicles
Operation of site plant and equipment
Embodied emissions of materials

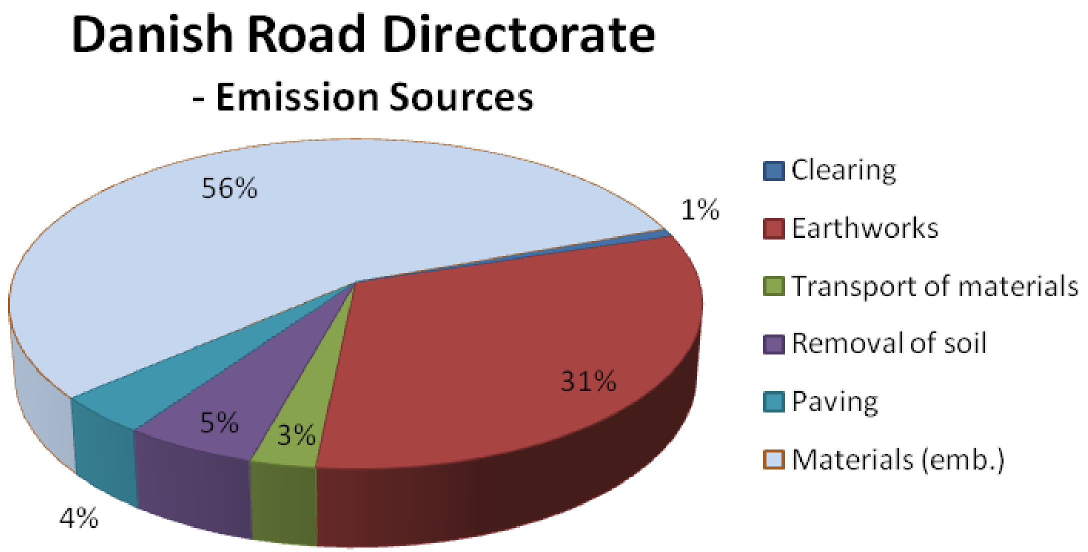
Deer Park Bypass
- Embodied Materials
10%
13%
15%
36%
11%
3%
11%
1%
0%
bitumen
cement
coarse aggregate
copper
fine aggregate
fly ash
imported fill
steel
Hot mix asphalt processing energy


Alpurt Motorway Extension
- Emission Sources (URS, 2008)
41%
21%
8%
12%
1%
12%
1%
2%
1%
1% 0%
Diesel
Electricity (incl loss)
Air Travel
Delivery vehicles
Office Waste
Aggregates
Cement
Lime
Steel
Asphalt
Vegetation clearance


Alpurt Motorway Extension
- Emission Sources (NSW RTA)
11%
4%
4%
34%
46%
1%
0%
0%
Vegetation clearance and transport
Use of purchased electricity
Operation of site vehicles
Operation of site plant and equipment
Detonation of explosives onsite
Waste transport and disposal to landfill
Transport of materials
Embodied emissions of materials

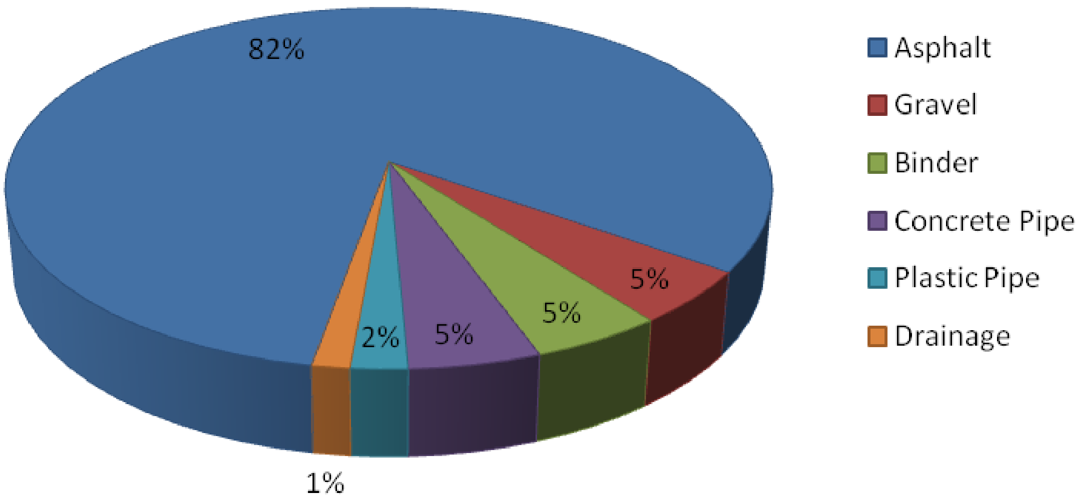


Alpurt Motorway Extension
- Embodied Materials (NSW RTA)
33%
2%
26%
32%
7%
cement
coarse aggregate
lime
steel
asphalt

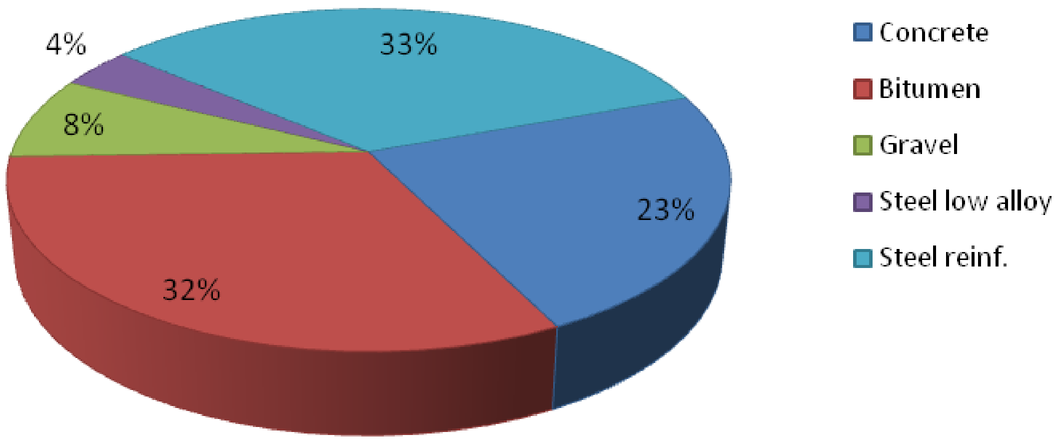



Danish Road Directorate
- Emission Sources
56%
1%
31%
5%
3%
4%
Clearing
Earthworks
Transport of materials
Removal of soil
Paving
Materials (emb.)

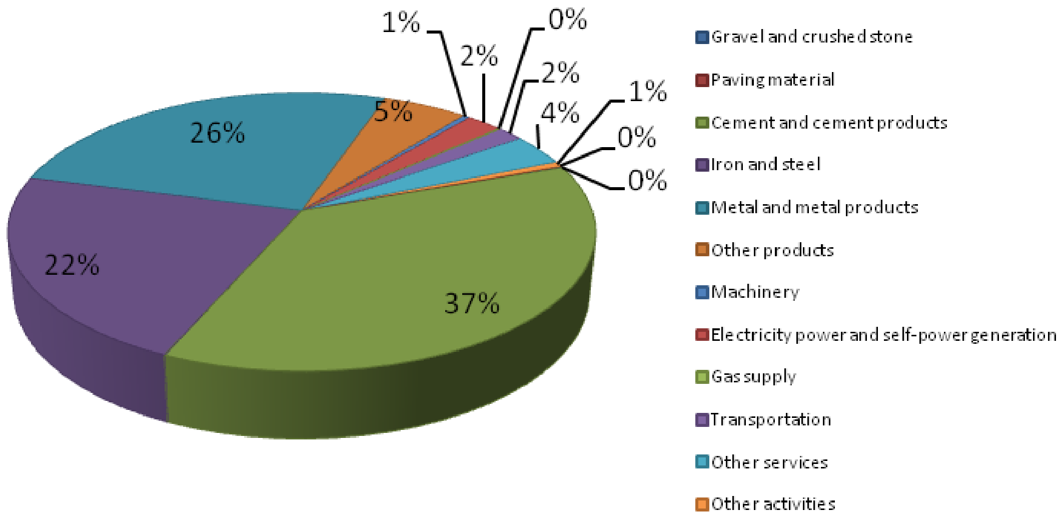
## Danish Road Directorate
### - Embodied Material

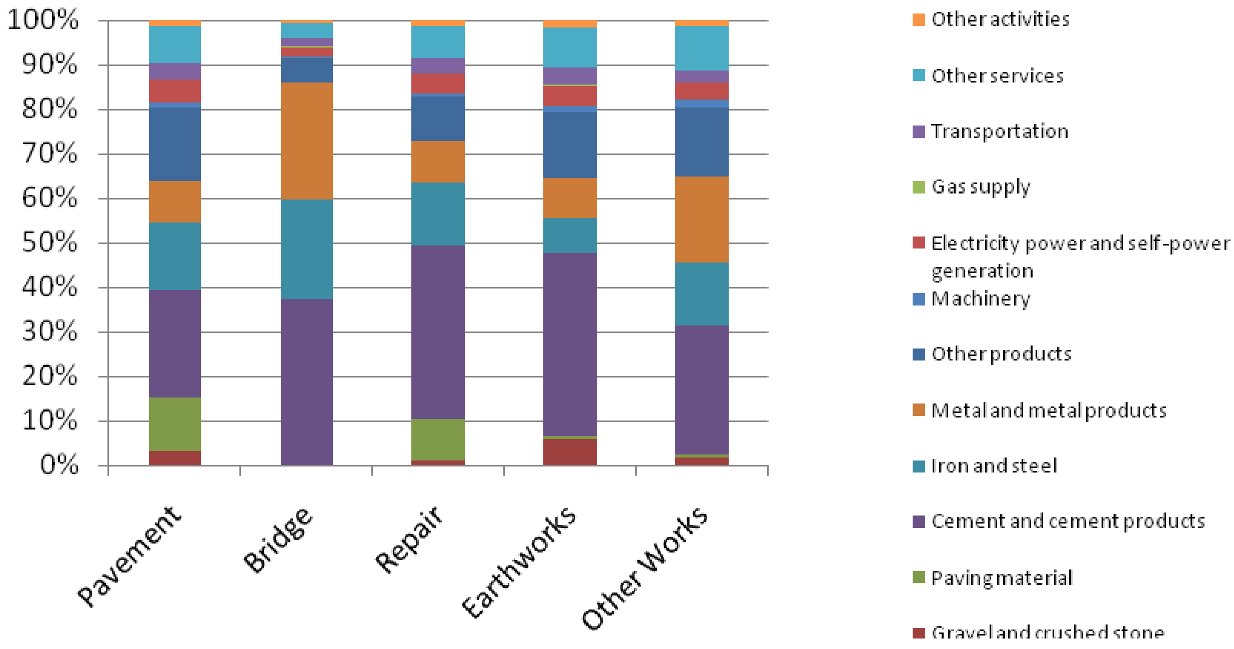



## Ecoinvent Road Construction
### - Embodied Matrials



# Tohoku Expressway Construction



# Appendix C

GHD Loss of Sequestration Supporting Document

# Transport Authority Greenhouse Group

## Vegetation emissions methodology for road construction

## Supporting Documentation

30 August 2012

*This report is subject to, and must be read in conjunction with, the limitations set out below and the assumptions and qualifications contained throughout the Report.*

*This report: has been prepared by GHD for Roads and Maritime Services* and VicRoads on behalf of the Transport Authority Greenhouse Group (TAGG) and *may only be used and relied on by TAGGfor the purpose agreed between GHD and the TAGGas set out in this report.*

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*GHD has not been involved in the preparation of the Greenhouse Gas Assessment Workbook for Road Projects and has had no contribution to, or review of the Greenhouse Gas Assessment Workbook for Road Projects other than in the Report for Vegetation emissions methodology for road construction workbook.GHD shall not be liable to any person for any error in, omission from, or false or misleading statement in, any other part of the Greenhouse Gas Assessment Workbook for Road Projects*

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# 1. Introduction

This report contains the supporting information for GHD's "Report for vegetation emissions methodology for road construction workbook" prepared for Roads and Maritime Services (RMS) and VicRoads on behalf of the Transport Authorities Greenhouse Group (TAGG). The key project requirements were to provide a user friendly methodology to estimate the amount of $CO_2$ sequestration potential lost due to vegetation removal associated with road projects. The aim was to identify an approach which did not require the project officer to model vegetation emissions and still provided a reasonable estimate of greenhouse gas emissions associated with vegetation removal. Detailed site specific modelling based on a flora survey is always preferable, however, the methodology developed and documented here allows a pragmatic estimate to be achieved based on site location and broad vegetation type.

This methodology also outlines how emission factors were derived for different vegetation types across Australia. The carbon sequestration potential of vegetation varies across the country based on numerous bio-geographic factors including rainfall, temperature, soil type and evaporation rates. To take these factors into account the Maximum Potential Biomass (here after referred to as "maxbio") layer was used. This layer was developed by the Australian Greenhouse Office (AGO) and incorporates climate data, soil data, solar radiation and leaf area index (Kesteven *et al.,* 2004) (refer to Section 2.2).

The amount of carbon sequestered by vegetation at a site varies with vegetation types and species. To define vegetation types this methodology used the National Vegetation Information System (NVIS) data, employed by the Commonwealth Department of Climate Change and Energy Efficiency (DCCEE) to estimate greenhouse gas (GHG) emissions for Australia's international reporting requirements.

First the maxbio data was consolidated into broad classes and maps showing the maxbio classes were created for each State (maxbio look up maps). Broad vegetation types were then defined based on the NVIS. The DCCEE's carbon accounting model, FullCAM, was used to calculate the carbon sequestration potential per hectare for each vegetation type in each maxbio class. These values, in tonnes of carbon per hectare, were converted to tonnes of carbon dioxide equivalent per hectare and used in the emission factors table presented in the Workbook. Each of these steps, the assumptions inherent to them, and their effect on the overall accuracy of the final values are further described in this report.

# 2. Methodology

## 2.1 Initial Assumptions

It was agreed by VicRoads and RMS representing TAGG that emission factors calculated should be conservative and that any necessary assumptions and simplifications of the data should be made in accordance with this intent. Carbon sequestration potential refers to the amount of carbon that it is possible for a certain type of vegetation to accumulate under the environmental conditions at that site. It takes into account carbon that exists in the vegetation at the time of clearing and carbon that could have been sequestered in the future if the vegetation was not cleared. For this reason vegetation was modelled to maturity (assumed to be 100 years) without any disturbance events such as fire or clearing. It was assumed that all carbon sequestration potential in the above and below ground carbon pools would be lost due to clearing. The health and state of the vegetation (i.e. remnant verses non-remnant, disturbed versus un-disturbed) was not taken into account.

## 2.2 Creating Maxbio Classes

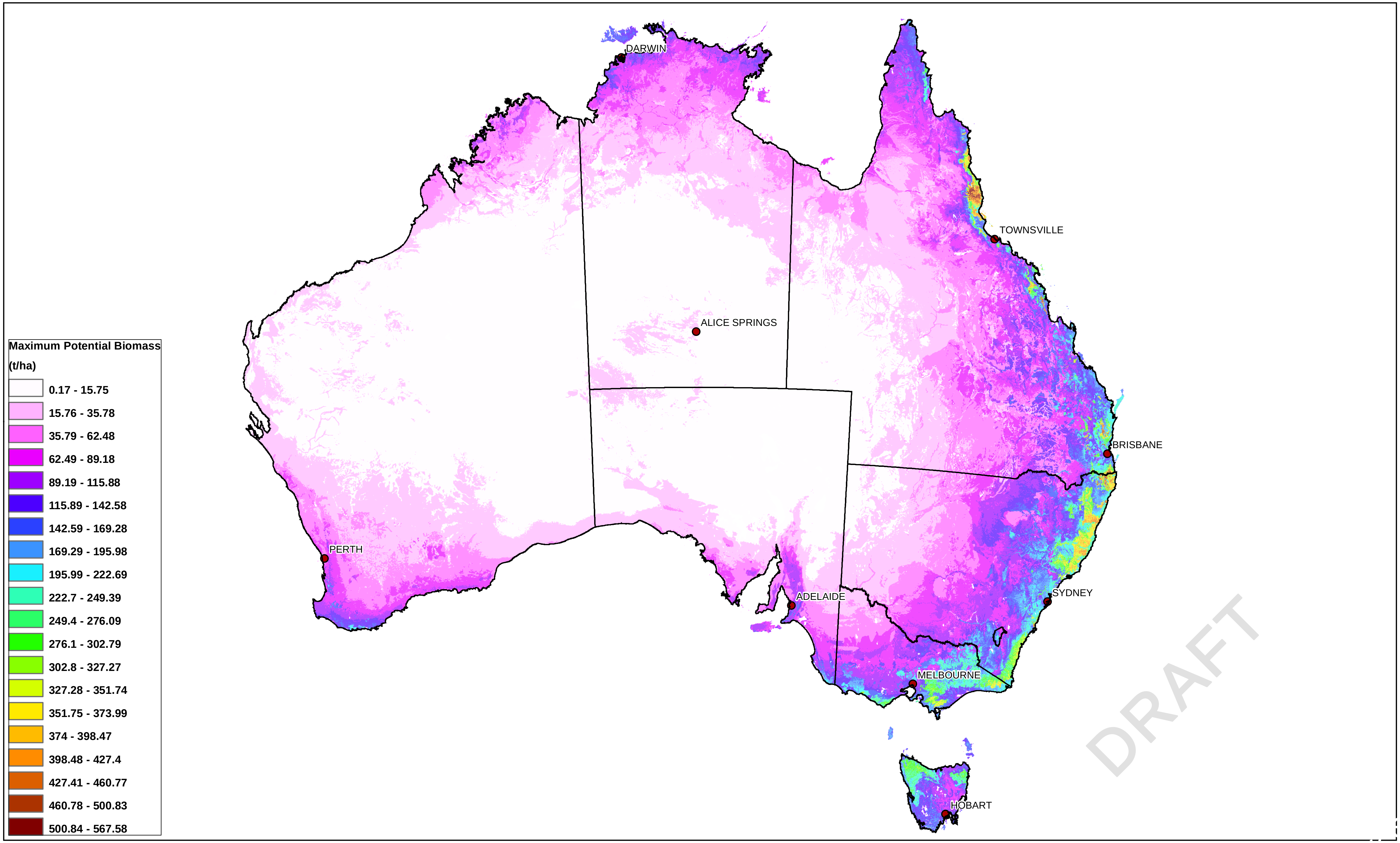
Maxbio data is measured in units of tonnes per hectare and is a continuous raster dataset covering the whole of Australia with a cell size of 0.0025 degrees (~250 m). Maxbio data is a regression of the Forest Productivity Index (FPI) which is derived from climate data, soil data, solar radiation and leaf area index (Kesteven*et al.* 2004). It estimates the above-ground biomass at a site assuming that the site was forested. Because the data is so detailed and covers such a large area it is difficult to determine the maxbio value at a given location without using a Geographic Information System (GIS).

To create easily distinguishable maxbio classes for use in the maxbio look-up maps it was necessary to simplify, classify and smooth the original maxbio data layer (Figure 1). To create the maxbio classes a series of analyses were performed using ESRI Arc GIS Version 10 these are outlined in Table 2.

The cell size was increased to approximately 5 km by 5 km (Step 1, Table 2). The maxbio values were then classified into 7 ranges (Table 1and Step 2, Table 2). The ranges were chosen based on the distribution of maxbio values throughout the country. The first three classes increase in increments of 50 up to 150 as this is where the majority of values fall. After 150, increments of 100 are used. Some FullCAM analysis of these ranges was conducted and they were found to provide suitable classes. A ‘majority filter’ tool was then used to smooth the data removing isolated pixels and replacing them with the value of surrounding pixels (Steps 3 and 4, Table 2).

## Table 1 Maxbio Classes Defined

| Maxbio class | Maxbio range (tonnes dry matter/hectare) |
|---|---|
| 1 | 0 - 50 |
| 2 | 50 - 100 |
| 3 | 100- 150 |
| 4 | 150 - 250 |
| 5 | 250-350 |
| 6 | 350-450 |
| 7 | >450 |




1:16,000,000 (at A3)

0 75 150 300 450 600

Kilometers

Horizontal Datum: Geocentric Datum of Australia (GDA)
Projection: GDA 1994 Geoscience Australia Lambert

CLIENTS | PEOPLE | PERFORMANCE

RMS and VicRoads
Revised Vegetation Emissions Methodology

# Maximum Potential Biomass Australia

| | |
|---|---|
| Job Number | 21-21553 |
| Revision | A |
| Date | 30 May 2012 |

Figure 1

Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

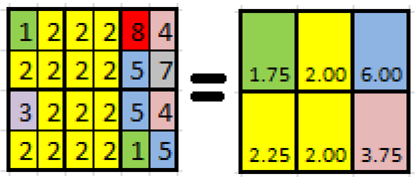
G:\21\21553\GIS\Maps\MXD\2121553_Z004_MaxBioOverview_RevA.mxd



Data Source: Geoscience Australia: 250k Data - Jan 2011; Department of Climate Change and Energy Efficiency: Maximum Potential Biomass, 2004. Created by: sjduce

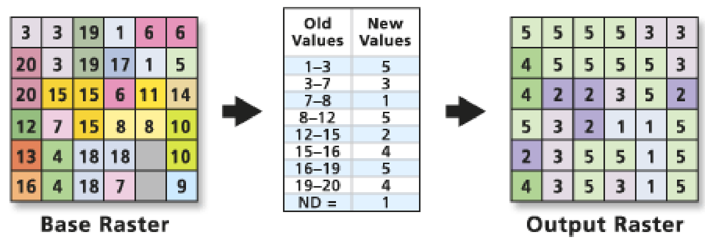
## Table 2: Creation of Maxbio Classes - GIS Methodology

<table>
<tr><th>Step</th><th>Data Layer Name</th><th>Resolution (approximate)</th><th>Processing</th><th>Description</th></tr>
<tr><td></td><td>Original Maximum Aboveground Biomass (Maxbio)</td><td>250m * 250m</td><td>-</td><td>Raw Dataset</td></tr>
<tr><td>1</td><td>Maxbio Aggregated</td><td>5km * 5km</td><td>Aggregate</td><td>To create 5 km by 5km cells the average value of the 250 m input cells within the area is calculated.

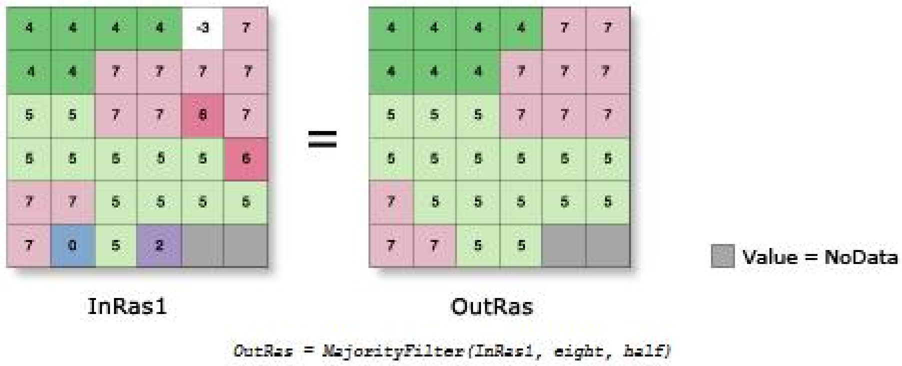


</td></tr>
<tr><td>2</td><td>Maxbio Aggregated Reclassified</td><td>5km * 5km</td><td>Reclassify</td><td>The aggregated cells are grouped into the following classes of maxbio value:

<table>
<tr><th>Potential biomass range</th><th>Potential biomass class</th></tr>
<tr><td>0 - 50</td><td>1</td></tr>
<tr><td>50 - 100</td><td>2</td></tr>
<tr><td>100- 150</td><td>3</td></tr>
<tr><td>150 - 250</td><td>4</td></tr>
<tr><td>250-350</td><td>5</td></tr>
<tr><td>350-450</td><td>6</td></tr>
<tr><td>>450</td><td>7</td></tr>
</table>




*(Source: ESRI, ArcGIS 10 Help)*</td></tr>
</table>

| Step | Data Layer Name | Resolution (approximate ) | Processing | Description |
|---|---|---|---|---|
| 3 | Maxbio Aggregated Reclassified Smoothed once | 5km * 5km | Majority Filter | This tool replaces the cells in a raster based on the majority of their contiguous neighbouring cells. This analysis looked at the closest 8 cells. If less than half the surrounding cells (i.e. less than four out of eight cells) had the same value the value was changed.<br><br>*(Source: ESRI, ArcGIS 10 Help)* |
| 4 | Maxbio Aggregated Reclassified Smoothed twice | 5km * 5km | Majority Filter 2 | The step described above was repeated. |

### 2.2.1 Accuracy

As is the case with all simplification, the analyses described above, result in the loss of detail and accuracy from the original maxbio dataset. To assess the amount accuracy that was lost throughout the GIS processing, a confusion matrix was created. Two hundred random points were generated in each maxbio class. The original maxbio value at each point was compared with the maxbio class the point was finally classified as. This determines what proportion of points was correctly or incorrectly classified and which maxbio classes were most commonly confused.

Table 3 shows that on average 75% of cells were correctly classified. The lower classes, 1 and 2, were the most often correctly classified while the upper class (7) was the most often incorrectly classified. This is because the highest maxbio areas are usually relatively small in size occurring where conditions are perfect for biomass production. For example, some parts of mountain ranges have high maxbio values, but because of the relatively rapid changes in elevation, rainfall and aspect in mountainous environments, they can have heterogeneous maxbio values surrounding them. However, in the highest two maxbio classes (6 and 7) very few points were classified as being lower than their original value, it was more common for points to be incorrectly classified into the higher class. This is in keeping with producing a conservative estimate of emission factors.

**Table 3: Confusion matrix comparing original maxbio class and final maxbio class**

| | Original Class | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Final Class | 1 | 2 | 3 | 4 | 5 | 6 | 7 | No value | Total points | % correctly classified points | % points originally greater than final class |
| 1 | 195 | **5** | | | | | | | **200** | **97.5%** | **2.5%** |
| 2 | **24** | 161 | **13** | | | | | **2** | **200** | **81.3%** | **6.6%** |
| 3 | | **34** | 139 | **19** | | | | **8** | **200** | **72.4%** | **9.9%** |
| 4 | | **5** | **29** | 137 | **18** | **1** | | **10** | **200** | **72.1%** | **10.0%** |
| 5 | | | | **26** | 140 | **27** | **3** | **4** | **200** | **71.4%** | **15.3%** |
| 6 | | | | **4** | **33** | 135 | **16** | **12** | **200** | **71.8%** | **8.5%** |
| 7 | | | | **4** | **2** | **79** | 115 | | **200** | **57.5%** | **0.0%** |
| **Total** | **219** | **205** | **181** | **190** | **193** | **242** | **134** | **36** | **1400** | | |

### 2.2.2 Scale and Resolution

To make the final map easy to read at a state-wide scale, it was necessary to reduce the resolution of the cells. The coarse resolution of the final maxbio layer (~5 km grid cells) gives the map a blocky appearance at the boarders resulting in some parts of cells falling outside the mainland boundary and other areas appearing to be missing. It also has the effect of appearing to join islands to the coast when they are separated by a narrow body of water. These factors are a product of the coarse resolution of the data and cannot be avoided.

## 2.3 Creation of Broad Vegetation Types

The National Vegetation Inventory System (NVIS) Major Vegetation Groups (MVGs) were used to define vegetation types in this project (Executive Steering committee for Australian Vegetation information, 2003). These groupings can be modelled directly in FullCAM and are consistent with those used for greenhouse gas accounting at a national level. The MVGs are described in detail, including pictures, species compositions and distribution in the Australian Government's Australian Natural Resources Atlas (ANRA) (http://www.anra.gov.au/topics/vegetation/pubs/native_vegetation/vegfsheet.html).

For the purposes of the Workbook vegetation classes need to be easily identifiable on-site to someone who may not have a background in ecology or botany. To create easily distinguishable vegetation classes that are meaningful from a carbon sequestration perspective the MVGs were grouped into nine classes (Table 4). These classes were grouped based on the partitioning of biomass (i.e. allocation to stems, branches, roots) used for each group in FullCAM (refer to Table 4) (DCCEE, 2012). Similarities in the broad structural formation and growing environment of vegetation were also taken into account in creating classes.

## Table 4: Vegetation classification based on the NVISMVGs

(*Source: DCCEE, 2012, National Inventory Report 2010 Volume 2, p.152)

| Vegetation Class | Name | Major Vegetation Groups (including hyperlinks to ANRA Fact Sheets) | Yield Allocation of Stems (fraction)* | Yield Allocation to Branches (fraction)* | Yield Allocation to Bark (fraction)* | Yield Allocation to Leaves (fraction)* | Yield Allocation to Coarse Roots (fraction)* | Yield Allocation to Fine Roots (fraction)* |
|---|---|---|---|---|---|---|---|---|
| A | Rainforest and vine thicket | Rainforest and Vine Thickets | 0.78 | 0.06 | 0.06 | 0.01 | 0.06 | 0.03 |
| B | Eucalypt Tall Open Forest | Eucalypt Tall Open Forest | 0.67 | 0.09 | 0.1 | 0.02 | 0.08 | 0.04 |
| C | Open Forest | Eucalypt Open Forest | 0.45 | 0.12 | 0.1 | 0.02 | 0.25 | 0.06 |
| | | Melaleuca Forest and Woodland | 0.42 | 0.15 | 0.1 | 0.02 | 0.25 | 0.06 |
| | | Eucalypt Low Open Forest | 0.45 | 0.12 | 0.1 | 0.02 | 0.25 | 0.06 |
| D | Open Woodlands | Acacia Forest and Woodland | 0.42 | 0.15 | 0.1 | 0.02 | 0.25 | 0.06 |
| | | Eucalypt Woodland | 0.44 | 0.15 | 0.1 | 0.02 | 0.23 | 0.06 |
| | | Eucalypt Open Woodland | 0.41 | 0.18 | 0.1 | 0.02 | 0.23 | 0.06 |
| | | Casuarina Forest and Woodland | 0.42 | 0.15 | 0.1 | 0.02 | 0.25 | 0.06 |
| | | Tropical Eucalypt Woodland/Grassland | 0.41 | 0.18 | 0.1 | 0.02 | 0.23 | 0.06 |
| | | Other Forests and Woodland | 0.42 | 0.15 | 0.1 | 0.02 | 0.25 | 0.06 |
| E | Callitris Forest and Woodland | Callitris Forest and Woodland | 0.42 | 0.15 | 0.1 | 0.02 | 0.16 | 0.15 |
| F | Mallee and Acacia Woodland and Shrubland | Mallee Woodland and Shrubland | 0.22 | 0.165 | 0.1 | 0.025 | 0.42 | 0.07 |
| | | Low Closed Forest and Closed Shrubland | 0.22 | 0.165 | 0.1 | 0.025 | 0.42 | 0.07 |
| | | Acacia Open Woodland | 0.22 | 0.165 | 0.1 | 0.025 | 0.42 | 0.07 |
| G | Open Shrubland | Acacia Shrubland | 0.22 | 0.165 | 0.1 | 0.025 | 0.25 | 0.24 |
| | | Other Shrubland | 0.22 | 0.165 | 0.1 | 0.025 | 0.25 | 0.24 |
| | | Unclassified Native Vegetation | 0.39 | 0.14 | 0.09 | 0.02 | 0.25 | 0.11 |
| H | Heathlands | Heathlands | 0 | 0.3 | 0.18 | 0.03 | 0.25 | 0.24 |
| | | Chenopod Shrub, Samphire Shrub and Forbland | 0 | 0.3 | 0.18 | 0.03 | 0.25 | 0.24 |
| I | Grassland | Tussock Grassland | | | | | | |
| | | Hummock Grassland | | | | | | |
| | | Other Grassland, Herbland, Sedgeland and Rushland | | | | | | |

## 2.4 Determining representative Major Vegetation Groups

Some of the nine vegetation classes created contain more than one MVG. In these cases it was necessary to choose one MVG to represent that vegetation class for modelling in FullCAM. To determine how much the MVG chosen affected the modelled carbon stock, different MVGs were modelled in FullCAM and compared. It was found that MVGs with exactly the same yield allocations (refer to Table 4) give equivalent results (all else being equal). In these cases any MVG could be used as representative of the vegetation class.

The Open Woodlands, Open Shrublands and Open Forest vegetation classes were composed of MVGs with differing yield allocations. The outcomes of FullCAM modelling at five different points for each MVG are presented in Table 5. Only the Open Shrubland MVGs showed any real difference.

It was determined that the MVG producing the highest carbon stocks should be used to ensure that the emission factors calculated would be conservative. The MVGs used to represent each vegetation class are presented in Table 6

**Table 5: Comparison of FullCAM results for different MVGs** (the MVG producing the highest carbon stock is in bold text)

| Vegetation class | Maximum Potential Biomass Class | Major Vegtation Group | Maximum Carbon Stock (tC/ha) | Minimum Carbon Stock (tC/ha) | Mean Carbon Stock (tC/ha) | Standard Deviation of Carbon Stocks |
|---|---|---|---|---|---|---|
| D - Open Woodlands | 4 | Eucalypt Woodland | 138 | 104 | 127 | 3 |
| | | **Acacia Forest and Woodlands** | **142** | **115** | **133** | |
| | | Tropical Eucalypt Woodland/Grassland | 138 | 112 | 130 | |
| G - Open Shrublands | 4 | **Acacia Shrubland** | **207** | **166** | **193** | 33 |
| | | Unclassified Native Vegetation | 156 | 126 | 146 | |
| C - Open Forest | 5 | Eucalypt Open Forest | 195 | 160 | 178 | 0.7 |
| | | **Melaleuca Forest and Woodland** | **196** | **160** | **179** | |

### Table 6 Representative MVG used for each Vegetation Class

| Vegetation Class | Name | Major Veg Group to use |
|---|---|---|
| **A** | Rainforest and Vine Thickets | Rainforest and Vine Thickets |
| **B** | Eucalypt Tall Open Forest | Eucalypt Tall Open Forest |
| **C** | Open Forest | Melaleuca Forest and Woodland |
| **D** | Open Woodlands | Acacia Forest and Woodland |
| **E** | Callitris Forest and Woodland | Callitris Forest and Woodland |
| **F** | Mallee and Acacia Woodland and Shrubland | Mallee and Acacia Woodland and Shrubland |
| **G** | Open Shrubland | Acacia Shrubland |
| **H** | Heathlands | Heathlands |
| **I** | Grassland | - |

GIS was used to examine the distribution of the vegetation classes created with respect to the maximum potential biomass classes. The results of analysing this are shown in Table 7. It shows that some vegetation classes never (black cells) or very rarely, less than 5% (blue cells) occurred in some maxbio classes. For example, vegetation class A (rainforest and vine thickets) never occurs in the lowest maxbio region as naturally rainforest could never establish or persist in such conditions. It is important to bear in mind that the data presented in Table 7 are based on two broad scale data sets (Maxbio and NVIS) which may have scale and accuracy issues. Therefore, there may be some differences between what actually exists on the ground and what is mapped.

### Table 7 Percentage of each vegetation class occurring in each maxbio class

| | Potential maximum biomass class | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Vegetation Class | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Total |
| A | 0% | 4% | 12% | 29% | 27% | 25% | 4% | 100% |
| B | 0% | 0% | 14% | 38% | 35% | 12% | 0% | 100% |
| C | 7% | 20% | 23% | 36% | 11% | 2% | 0% | 100% |
| D | 53% | 31% | 11% | 5% | 0% | 0% | 0% | 100% |
| E | 29% | 61% | 9% | 1% | 0% | 0% | 0% | 100% |
| F | 84% | 12% | 2% | 1% | 0% | 0% | 0% | 100% |
| G | 93% | 4% | 2% | 0% | 0% | 0% | 0% | 100% |
| H | 86% | 8% | 4% | 2% | 0% | 0% | 0% | 100% |
| I | 90% | 6% | 3% | 1% | 0% | 0% | 0% | 100% |

## 2.5 Modelling Carbon Sequestration

The carbon sequestration modelling was undertaken using the Nation Carbon Accounting Toolbox's (NCAT) carbon accounting model, FullCAM (*Version 3.13.8 (Research Edition))* (Richards *et al.*, 2005). The NCAT is the publically available version of the National Carbon Accounting System (NCAS) which is Australia's national methodology for accounting for carbon in the land sector.

FullCAM estimates carbon stocks and the transitions of carbon between different carbon pools in forest and agricultural systems. The model uses plot files which represent regions of land with the same characteristics. For the purpose of this study each vegetation class for each maxbio class was modelled as a single plot file (i.e. vegetation class one in maxbio class one).

### 2.5.1 Determining a modelling point

To model carbon sequestration FullCAM requires the input of a location point for each plot file. As such, it was necessary to select a representative modelling point for each maxbio class. To determine how much influence this point would have on the carbon stocks calculated and which point to choose as representative for each maxbio class, sensitivity analysis was performed at different points.

The original maxbio layer was examined and five points were chosen from each maxbio class in different locations using ArcGIS. To ensure a conservative estimate the points were chosen to be at the upper end of the maxbio class. For example, in class 3 (100-150) points which fell in areas with maxbio values between 145 and 150 were chosen.

Other factors including rainfall, evaporation layers and soil organic carbon content were also taken into account when choosing the points for each maxbio class. In all cases it was intended to choose points from a range of states, however, FullCAM lacks soil and crop data required to run the model in Western Australia and most of South Australia. Also, given the distribution of the highest maxbio values across Australia is along the east coast, the majority of the points chosen were consequently on the eastern seaboard.

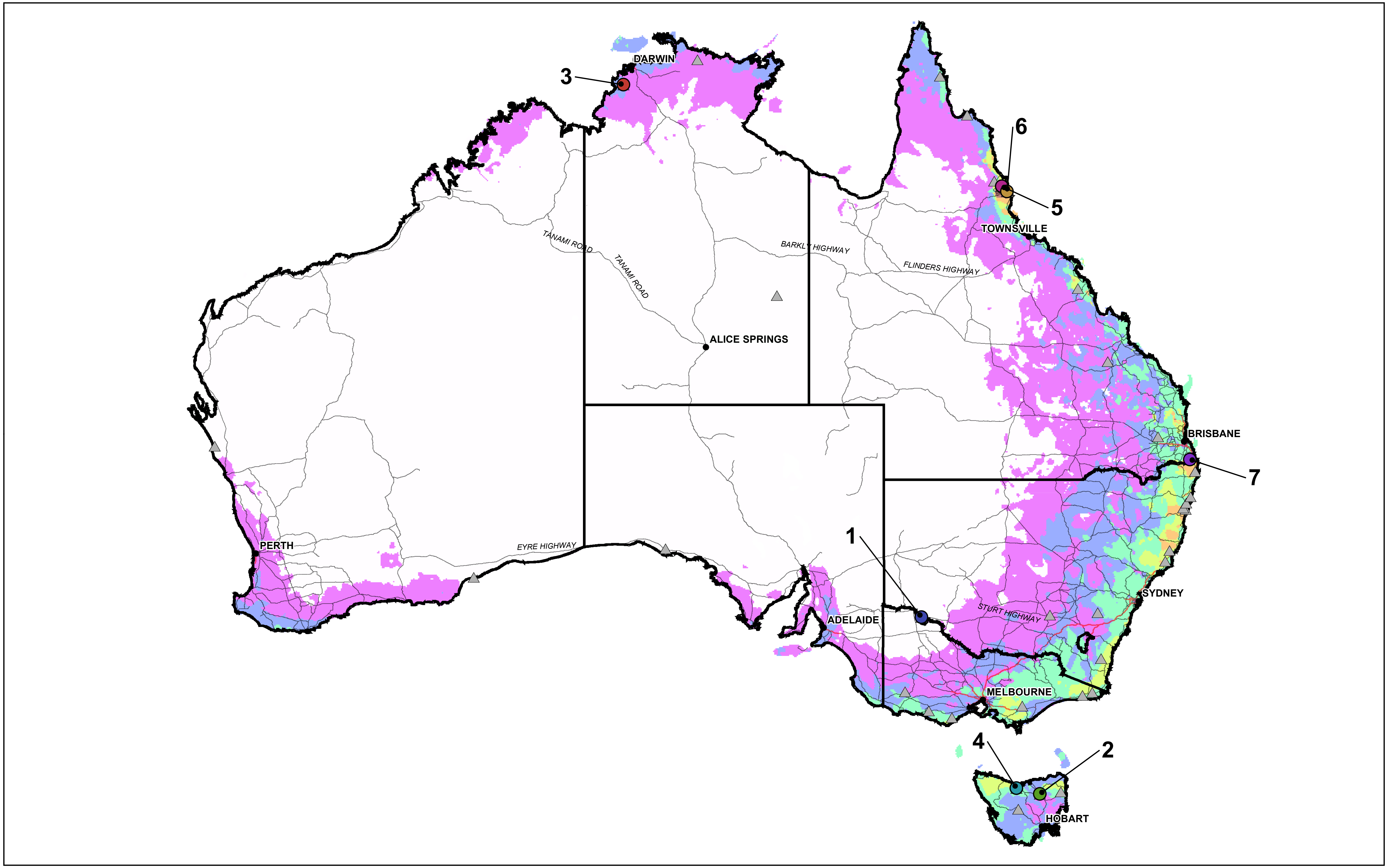
Table 8 presents the maximum, minimum, mean and standard deviation of the carbon stocks calculated at the five points in each maxbio class. It was shown that the location of the model point did influence the carbon stocks calculated to some extent. Standard deviation values between the five points tested in each maxbio class varied from three, in maxbio class one, to eighteen in maxbio class five. This difference was not considered substantial enough to warrant using the average result of multiple model location points. To ensure a conservative estimate, of the five points compared, those with the highest carbon stocks were used to represent the maxbio classes in calculating emissions for the emissions factor table. Table 9 and Figure 2 show the location of the model points chosen.

## Table 8 Comparison of carbon stock values calculated at five points in each maxbio class

| Maximum potential biomass class | Vegetation class | Maximum Carbon Stock (tC/ha) | Minimum Carbon Stock (tC/ha) | Mean Carbon Stock (tC/ha) | Standard Deviation of Carbon Stocks (tC/ha) |
|---|---|---|---|---|---|
| **1** | **Mallee and Acacia Woodland and Shrubland** | 29 | 15 | 24 | 6 |
| **2** | **Mallee and Acacia Woodland and Shrubland** | 78 | 72 | 74 | 3 |
| **3** | **Callitris Forests and Woodlands** | 86 | 68 | 79 | 8 |
| **4** | **Acacia Forest and Woodland** | 142 | 115 | 133 | 13 |
| **5** | **Melaleuca Forest and Woodland** | 196 | 160 | 179 | 18 |
| **6** | **Rainforests and Vine Thickets** | 155 | 142 | 150 | 5 |
| **7** | **Rainforests and Vine Thickets** | 205 | 188 | 195 | 9 |

## Table 9 Representative points chosen for each maxbio class

| Potential Maxbio class | Potential Maxbio Range | Model point latitude | Model point longitude |
|---|---|---|---|
| **1** | 0 - 50 | -34.50084 | 142.5055 |
| **2** | 50 - 100 | -41.5748 | 147.2504 |
| **3** | 100- 150 | -13.17290 | 130.57600 |
| **4** | 150 - 250 | -41.34500 | 146.30800 |
| **5** | 250-350 | -17.25088 | 145.7266 |
| **6** | 350-450 | -17.45020 | 145.93100 |
| **7** | >450 | -28.18350 | 153.24900 |




1:16,000,000 (at A3)

0 200 400 600 800

Kilometers

Horizontal Datum: Geocentric Datum of Australia (GDA) 1994

N

**Legend**

**Maxbio Class**

1, 2, 3, 4, 5, 6, 7

Other model points examined

Dual Carriageway

Capital Cities

Principal Road

**Maximum Potential Biomass Class**
**(tonnes dry matter/ha)**

Class 1: 0 - 50
Class 2: 50 - 100
Class 3: 100 - 150
Class 4: 150 -250
Class 5: 250 - 350
Class 6: 350 - 450
Class 7: >450

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TAGG
Revised Vegetation Emissions Methodology

| | |
|---|---|
| Job Number | 21-21553 |
| Revision | A |
| Date | 25 Jul 2012 |

Model Point Location
used for each Maxbio Class

Figure 2

G:\21\21553\GIS\Maps\MXD\2121553_Z022_ModelPointLocation_RevA.mxd



Data Source: Geoscience Australia: 250k Data - Jan 2011; Department of Climate Change and Energy Efficiency: Maximum Potential Biomass, 2004. Created by: sjduce

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

### 2.5.2 FullCAM Configuration

Plot files were configured as "Multilayer mixed (forest and agricultural) systems" in FullCAM. Where possible the default settings of FullCAM were used. The main deviation from the default settings was that the initial percentages of biomass existing in trees, and carbon mass existing in debris and soil were all set to zero. This ensured a more realistic rate of vegetation regrowth and carbon accumulation in the soil and debris pools (*pers.comm* Matt Searson, DCCEE, 2011). The maximum aboveground biomass for trees was reset to the upper limit for that maximum potential biomass class to ensure conservative results for each maxbio class. Full details of the configuration of *FullCAM* files used to model each emission factor are provided in Table 10 below.

**Table 10 FullCAM set-up used to model emission factors and case studies**

| Standard Model Set-up | |
|---|---|
| Timing | |
| **Start Date** | January, 1900 |
| **End Date** | December, 2012 |
| **Simulation Steps** | Monthly |
| **Output Steps** | Every 12 (ie. Yearly) |
| Plot | |
| **Configuration** | Multilayer mixed (forest and agricultural) system |
| **Inclusions** | Soil and minerals |
| Tree Production | |
| **Method** | Tree yield formula |
| Data Builder | |
| **Spatial data** | Latitude and Longitude from GIS (refer to Table 9) |
| **Forest percentage for downloading** | 100 |
| **Regional soils** | Default used |
| **Tree-species** | Native Forest Groups – then relevant MVG (refer to Table 9) |
| Data Inputs | |
| **Site** | Maximum Aboveground Biomass for trees reset to the upper limit for that maximum potential biomass class |
| **Trees; Crops; Soils** | Defaults used |
| Initial Conditions | |
| **Trees; Debris; Soil** | **All reset to zero** |
| Events | |
| **Thin (clearing)** | **1912 day 1; Standard values used** |
| **Plant Trees** | **1912 day 2; Standard values used** |

## 2.6 Carbon stocks calculated

Table 11 shows the cabon stocks calculated using FullCAM for each vegetation class in each maxbio class. As would be expected, carbon stocks increase as the maxbio class increases. The total carbon stocks calculated in this study compared reasonably well with those back-calculated from the Australian State of the Forests Report (SoF Report) when the numbers are compared to those calculated in the maxbio class the vegetation type would be expected to occur most commonly (Montreal Process Implementation Group for Australia, 2008) (refer to the last column in Table 11). For example, Table 7 shows that vegetation class B mostly occurs in maxbio classes 4 and 5. The value back calculated from the SoF Report (112 tC/ha) is between the values calculated in maxbio classes 4 (109 tC/ha) and 5 (150 tC/ha). Similarly vegetation class E occurs mostly in maxbio classes 2 and 1 with the back calculated value also falling between the two values calculated in these classes.

It was also identified that unrealistically high carbon stock values were calculated for vegetation classes that are unlikely to occur in high maxbio classes. For example open shrubland (vegetation class 7) results in carbon stocks almost double that of rainforest (vegetation class one) in the highest maxbio class (i.e. growing in an environment where it naturally would never occur) (Table 11). It is suggested that FullCAM may have been designed and calibrated to model vegetation classes in maxbio regions where they occur naturally. When it is used outside these conditions unrealistic values may be achieved.

The spatial intersection between the vegetation classes and Maxbio classes, presented in Table 7, found that some vegetation types never, or almost never, coincide with some maxbio classes. To avoid confusion and spurious vegetation class choices outside their natural range, emission factors were not provided for vegetation classes and maxbio classes which coincide less than one per cent of the time (shown as black cells in Table 11). Blue cells in Table 11 represent rare (less than 5% in Table 7) vegetation and maxbio class combinations. In these cases it is recommended that the vegetation class chosen be reviewed.  A ‘Mixed Species Environmental Planting” vegetation class was also modelled in addition to the nine vegetation classes but was not included in the emission factor table for the Workbook (Table 11).

### Table 11 Carbon stocks calculated for each vegetation class in each maxbio class (tonnes of carbon per hectare)

| | Potential maximum biomass class carbon stocks (tC/ha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Vegetation Class | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Total Carbon (tC/ha) Australia's State of the Forests Report 2008* |
| A | 16 | 42 | 62 | 105 | 145 | 162 | 209 | 220 |
| B | 16 | 44 | 64 | 109 | 151 | 168 | 218 | 112 |
| C | 21 | 57 | 84 | 142 | 196 | 218 | 282 | 28 |
| D | 21 | 57 | 84 | 142 | 196 | 218 | 282 | 61 |
| E | 22 | 59 | 86 | 147 | 201 | 224 | 290 | 40 |
| F | 29 | 78 | 114 | 194 | 267 | 298 | 386 | - |
| G | 31 | 83 | 120 | 207 | 281 | 313 | 405 | 63 |
| H | 31 | 84 | 122 | 209 | 284 | 316 | 409 | - |
| I*** | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 25** |

* Values were back-calculated based on forest biomass + soil carbon stocks (Mt) (Table 77, page 117) and forest areas (ha) (Table 1, page 4) presented in Australia's State of the Forests Report, 2008 (Montreal Process Implementation Group for Australia, 2008).

** This value is for the soil carbon component of grasslands only (ACS, 2012).

*** Refer to discussion in Section 2.7.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mixed species enviro. planting | 22.18 | 58.6 | 83.38 | 141.19 | 189.64 | 210.88 | 268.44 | |

## 2.7 Grassland Carbon Stocks

Grasslands in Australia are reported to cover an area of approximately 435 Ma (DCCEE, 2012) and span a wide range of ecosystems, from lush irrigated environments to arid and semi-arid conditions (Gifford, 2010). When determining the levels of carbon contained in grassland systems (i.e. carbon held in grass, debris and soil) the figures obtained through FullCAM are unreliable as the model is calibrated for high management environments, that is, regular crop rotation agricultural systems.

Native grassland systems, which are typically not subject to pasture improvement, demonstrate rapid increases in soil carbon and biomass when simulations are developed based on these lower management regimes. This is not representative of a normal grassed ecosystem, as the quantity of carbon stored in soil is finite (Powlson *et al*., 2011). Due to the unreliability of modelled data, a literature search was conducted to determine an approximation of carbon levels within grassland environments.

Studies conducted in 2005 indicated that Australian grassland systems store 25 t C $ha^{-1}$ in soil carbon with mixed tree grassland (savannah) systems storing soil carbon in the range of 30-70 t C $ha^{-1}$ (ACS, 2012). More recent studies report soil carbon stocks in Australian grazing lands to fall within the range of 60 t C $ha^{-1}$, based on a representative grassland system which includes trees as well as grazable grasses and herbs (Gifford, 2010). Soil carbon stocks were calibrated at 29.5 t C $ha^{-1}$ within the *FullCAM* model when using information collated from 29 sites across a range of soil types in both northern and southern Australia (DCCEE, 2012).

Therefore, it can be assumed that soil carbon stocks within grassland systems fall within a range of 25-30 t C $ha^{-1}$ with additional vegetation (e.g. dispersed shrubs or trees) contributing between 30–40 t C $ha^{-1}$. Based on the conservative approach which has been adopted across this emission factor methodology it is recommended that a standard value of 30 t C $ha^{-1}$ be adopted across all maxbio classes, assuming a non-mixed (i.e. no trees and shrubs) grassland ecosystem. This allows for a contribution of biomass vegetation to carbon storage. However, it should be noted that such a figure does not account for the contribution of dispersed shrub and tree vegetation within a grassland system to carbon stocks.

## 2.8 Degraded Vegetation

The methodology utilised assumes that the vegetation has achieved maturity. The health and state of the vegetation (such as remnant verses non-remnant/regrowth, disturbed versus un-disturbed, drought or insect affected) was not taken into account with the conservative assumption being that the vegetation is healthy (as perhaps it would have been before any road related activities occurred). However, it is recognised that the vegetation existing at a specific site may be regrowth on previously cleared land (e.g. for farmland) that is difficult to assign to one of the broad vegetation classes identified. In such cases it is recommended that a woodland or shrubland vegetation class be used depending on the density and size of vegetation present.

In situations where a single mature, remnant tree exists in an otherwise grassland area it is considered that the grassland category is suitable as the amount of carbon sequestration potential generated, even by a large tree, is negligible when considered in tonnes of $CO_2$ equivalent per hectare. For example a mature 50 cm diameter yellow box tree (*Eucalyptus melliodora*) contains approximately 0.67 tC/ha (total above and below ground biomass) (Lachlan CMA carbon calculator (CSIRO/Lachlan CMA/GHD 2010). In the context of a grassland environment with an emission factor of 110 tC/ha this is not a substantial contribution.

## 2.9 Calculating Final Emission Factors

To calculate emission factors the carbon stocks in tonnes of carbon per hectare (Table 11) were converted to carbon dioxide equivalent by multiplying the carbon stock by

3.67 (the factor to convert from elemental mass of a gas species to molecular mass) (DCCEE, 2012). These values are presented in Table 12.

### Table 12 Emission Factors (t $CO_2$-e/ha)

| | Potential maximum biomass class | | | | | | |
|---|---|---|---|---|---|---|---|
| Vegetation Class | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| A | | | 227 | 384 | 532 | 594 | 768 |
| B | | | 237 | 401 | 554 | 618 | |
| C | 77 | 209 | 307 | 521 | 718 | | |
| D | 77 | 209 | 307 | | | | |
| E | 80 | 217 | 316 | | | | |
| F | 106 | 287 | | | | | |
| G | 113 | | | | | | |
| H | 115 | 309 | | | | | |
| I | 110 | 110 | 110 | 110 | 110 | 110 | 110 |

To determine the emissions associated with vegetation clearing multiply the area of vegetation with the corresponding emission factor (taken from Table 12), and sum for all vegetation classes using equation 1.

$$E_{veg} = \sum A_{ij} EF_{ij} \qquad \text{(equation 1)}$$

Where:

$E_{veg}$ is the total greenhouse gas emissions from vegetation removal for the project, in tonnes of carbon dioxide equivalent (t $CO_2$-e)

$A_{ij}$ is the area of vegetation to be removed in Maximum Potential Biomass Class *i* and Vegetation Class *j*, in hectare (ha)

$EF_{ij}$ is the emission factor from Table 12 for Maximum Potential Biomass Class *i* and Vegetation Class *j*, in tonnes of carbon dioxide equivalent per hectare (t $CO_2$-e/ha).

## 2.10 Comparison to Case Studies

The results of FullCAM modelling for five case study sites, provided by members of TAGG, were compared to the emission factors calculated in the look-up table (refer to Table 13). The case studies were modelled using the location of the site, the original maxbio value at the site and the MVG that best fit the vegetation at the site. All other parameters used in FullCAM were the same as those documented in Table 10. Thus, the case study values should represent an estimate of carbon sequestration potential as close to reality as possible.

Table 13 shows that in each case the GHG emissions calculated using the emission factor look-up table were higher than those calculated in the case study. This is to be expected as through-out the process a conservative approach was taken choosing the highest maxbio representative modelling point (Section 2.5.1), vegetation class with the highest carbon stocks (Section 2.4) and using the upper maxbio value in the range (Section 2.5.2).

The greatest variation between case study value and look-up table value is 53% for the WA case study. The original maxbio value at the site is 24 tonnes dry matter per hectare where as a maxbio value of 50 was used when modelling the value for the emission factor look-up table. This explains why the value is slightly higher. While 53% is a considerable difference, when put in the context of the total emissions associated with a road project and the TAGG whole of life methodology, the vegetation component is likely to be very small, particularly in such a low maxbio area.

Variation between case study and look-up table values is lowest in the higher maxbio classes. These results are in keeping with the intent of the workbook to provide broad scale and conservative estimations of carbon emissions based on limited information.

**Table 13 GHG emissions for case study sites (blue headed columns) compared with those calculated using the emission factor look-up table (green headed columns).**

| State | Project Name | Latitude | Longitude | Maxbio (tonnes dry matter/ ha) | Veg. Type | Area of Clearing (ha) | Corresponding MVG in FullCAM | Carbon Stock in Mature Veg (t/ha) | GHG Emissions based on FullCAM (t CO2-e) | Maxbio Class | Veg. Class | Emission Factor (t C/ha) | GHG Emissions based on emission factors (t CO2-e) | Difference between FullCAM and emission factors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vic. | Princes Highway West Portland to Heywood | -38.2374 | 141.629 | 194 | Herb-rich Foothill Forest | 1.06 | Eucalypt Open Forest | 110 | 3,594 | 4 (150-250) | 3 | 142 | 4,742 | 32% |
| | | | | | Damp Heathy Woodland | 6.1 | Eucalypt Woodlands | 107 | | | 4 | 142 | | |
| | | | | | Damp Sands Herb-rich Woodland | 1.87 | Eucalypt Woodlands | 107 | | | 4 | 142 | | |
| | | | | | Lowland Forest | 0.07 | Eucalypt Woodlands | 107 | | | 4 | 142 | | |
| WA* | Eyre Highway (Goldfields-Esperance) | -32.332395 | 125.0105 | 24 | Medium woodland; goldfield eucalypts / Succulent steppe with open low woodland; myoporum over saltbush, merrit& red mallee | 27.3 | Mallee Woodland and Shrubland | 19 | 1,897 | 1 (0-50) | 6 | 29 | 2,906 | 53%* |

| State | Project Name | Latitude | Longitude | Maxbio (tonnes dry matter/ ha) | Veg. Type | Area of Clearing (ha) | Corresponding MVG in FullCAM | Carbon Stock in Mature Veg (t/ha) | GHG Emissions based on FullCAM (t CO2-e) | Maxbio Class | Veg. Class | Emission Factor (t C/ha) | GHG Emissions based on emission factors (t CO2-e) | Difference between FullCAM and emission factors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NSW | Tintenbar to Ewingsdale | -28.6965 | 153.531 | 354 | Lowland Rainforest | 2 | Rainforest and Vine Thicket | 148 | 1,087 | 6 (350-450) | A | 162 | 1,189 | 9% |
| NSW | Hume Highway Woomargama to Mullengandra | -35.830002 | 147.22701 | 79 | Eastern Rainshadow Woodland | 4.16 | Eucalypt woodlands | 43 | 2,588 | 2 (50-100) | D | 57 | 3,393 | 31% |
| | | | | | Tablelands Riparian Woodlands | 9.55 | Eucalypt woodlands | 43 | | | D | 57 | | |
| | | | | | White Box Yellow Box Redgum Woodland | 2.51 | Eucalypt woodlands | 43 | | | D | 57 | | |
| QLD | Cairns Bruce Highway Upgrade | -16.975 | 145.743 | 287 | Regional Ecosystem 7.3.12 | 0.05 | Eucalypt Tall Open Forest | 125 | 1,278 | 5 (250 - 350) | B | 151 | 1,545 | 21% |
| | | | | | Regional Ecosystem 7.11.18 | 2.11 | Eucalypt Low Open Forest | 162 | | | C | 196 | | |

* There was no crop or soil data available in FullCAM at this site. Therefore, crop and soil values for the representative point chosen in maxbio class 1 (refer to Table 9) were input.

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GHD

133 Castlereagh St  Sydney NSW 2000
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T: 2 9239 7100   F: 2 9239 7199   E: sydmail@ghd.com.au



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| B | Felicity Muller | D. Adshead | | D. Adshead | | 25-06-2012 |
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